Total System Performance Assessment
Model/Analysis for the License Application
Addendum 01

Volume I

Prepared for:
U.S. Department of Energy
Office of Civilian Radioactive Waste Management
Office of Repository Development
1551 Hillshire Drive
Las Vegas, Nevada 89134-6321

Prepared by:
Sandia National Laboratories
OCRWM Lead Laboratory for Repository Systems
1180 Town Center Drive
Las Vegas, Nevada 89144

Under Contract Number
DE-AC04-94AL85000
DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, nor any of their contractors, subcontractors or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or any third party’s use or the results of such use of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof or its contractors or subcontractors. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.
# Addendum Cover Page

**Complete only applicable items.**

1. Total Pages: ~794

2. Addendum to (Title):

Total System Performance Assessment Model/Analysis for the License Application: Addendum

3. DI (including Revision and Addendum No.):

MDL-WIS-PA-000005 REV 00 AD 01

<table>
<thead>
<tr>
<th>Printed Name</th>
<th>Signature</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patrick D. Mattie - Lead</td>
<td></td>
<td>3-11-08</td>
</tr>
<tr>
<td>Mel Marietta</td>
<td></td>
<td>3/11/2008</td>
</tr>
<tr>
<td>John Devers - Lead</td>
<td></td>
<td>03/11/08</td>
</tr>
<tr>
<td>Jerry McNeish</td>
<td></td>
<td>3/11/08</td>
</tr>
<tr>
<td>M. Kathryn Knowles - PASI Manager</td>
<td></td>
<td>3/11/08</td>
</tr>
</tbody>
</table>

10. Remarks

---

**Change History**

<table>
<thead>
<tr>
<th>Revision and Addendum No.</th>
<th>Description of Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rev.00 AD 01</td>
<td>This addendum presents updated analyses for the TSPA-LA Rev 00 and any changes to the parent document necessary to document these updated analyses. The updated analyses include updates to direct inputs of the TSPA-LA. In addition, issues identified in Appendix P of the parent document are addressed here per the review criteria outlined in Sections 2.1.4 and 2.3.5.2.1 of the Technical Work Plan for: Total System Performance Assessment FY 07-08 Activities (SNL 2008 [DIRS 184920]).</td>
</tr>
<tr>
<td>CONTENTS</td>
<td>Page</td>
</tr>
<tr>
<td>----------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>ES1[a] SCOPE.................................................................................. ES-1[a]</td>
<td></td>
</tr>
<tr>
<td>ES1.1[a] Introduction..................................................................... ES-1[a]</td>
<td></td>
</tr>
<tr>
<td>ES2[a] TOTAL SYSTEM PERFORMANCE ASSESSMENT METHODOLOGY .............. ES-2[a]</td>
<td></td>
</tr>
<tr>
<td>ES3[a] TSPA-LA MODEL DEVELOPMENT PROCESS .................................. ES-3[a]</td>
<td></td>
</tr>
<tr>
<td>ES3.1[a] Features, Events, and Processes Analysis......................... ES-3[a]</td>
<td></td>
</tr>
<tr>
<td>ES3.2[a] Development of the Scenario Classes ................................ ES-3[a]</td>
<td></td>
</tr>
<tr>
<td>ES3.3[a] Incorporation of Uncertainty......................................... ES-3[a]</td>
<td></td>
</tr>
<tr>
<td>ES3.4[a] Natural and Engineered Model Components......................... ES-4[a]</td>
<td></td>
</tr>
<tr>
<td>ES3.5[a] Alternative Conceptual Models .. ..................................... ES-4[a]</td>
<td></td>
</tr>
<tr>
<td>ES3.6[a] Configuration Management for the TSPA-LA Model ................ ES-4[a]</td>
<td></td>
</tr>
<tr>
<td>ES4[a] YUCCA MOUNTAIN SITE DESCRIPTION .................................... ES-4[a]</td>
<td></td>
</tr>
<tr>
<td>ES4.1[a] Physiographic Setting and Topography ................................ ES-4[a]</td>
<td></td>
</tr>
<tr>
<td>ES4.2[a] Climate........................................................................... ES-4[a]</td>
<td></td>
</tr>
<tr>
<td>ES4.3[a] Geology............................................................................ ES-4[a]</td>
<td></td>
</tr>
<tr>
<td>ES4.4[a] Regional Tectonic Setting............................................. ES-4[a]</td>
<td></td>
</tr>
<tr>
<td>ES5[a] THE REPOSITORY SUBSURFACE FACILITY AND ENGINEERED BARRIER SYSTEM ..................................... ES-4[a]</td>
<td></td>
</tr>
<tr>
<td>ES6[a] NATURAL AND ENGINEERED BARRIERS .................................... ES-4[a]</td>
<td></td>
</tr>
<tr>
<td>ES7[a] GENERAL DESCRIPTION OF THE TSPA-LA MODEL .................... ES-5[a]</td>
<td></td>
</tr>
<tr>
<td>ES8[a] VERIFICATION/VALIDATION OF THE TOTAL SYSTEM PERFORMANCE ASSESSMENT MODEL ..................................... ES-5[a]</td>
<td></td>
</tr>
<tr>
<td>ES8.1[a] Verification and Validation Strategy .............................. ES-5[a]</td>
<td></td>
</tr>
<tr>
<td>ES8.2[a] Computer Code and Input Verification ................................ ES-5[a]</td>
<td></td>
</tr>
<tr>
<td>ES8.3[a] Stability Testing.............................................................. ES-6[a]</td>
<td></td>
</tr>
<tr>
<td>ES8.4[a] Uncertainty Characterization Reviews .............................. ES-7[a]</td>
<td></td>
</tr>
<tr>
<td>ES8.5[a] Surrogate Waste Form Validation ..................................... ES-7[a]</td>
<td></td>
</tr>
<tr>
<td>ES8.6[a] Corroboration of Abstraction Model Results with Validated Process Models ................................................. ES-7[a]</td>
<td></td>
</tr>
<tr>
<td>ES8.7[a] Auxiliary Analyses.............................................................. ES-7[a]</td>
<td></td>
</tr>
<tr>
<td>ES8.8[a] Confidence Building: Natural Analogues................................ ES-9[a]</td>
<td></td>
</tr>
<tr>
<td>ES8.9[a] Summary of Technical Reviews ......................................... ES-9[a]</td>
<td></td>
</tr>
<tr>
<td>ES9[a] SYSTEM PERFORMANCE ANALYSES ........................................ ES-9[a]</td>
<td></td>
</tr>
<tr>
<td>ES9.1[a] Total Mean Annual Dose to the Reasonably Maximally Exposed Individual for the Repository System ............................... ES-10[a]</td>
<td></td>
</tr>
<tr>
<td>ES9.2[a] Results of the Scenario Class Modeling Case Simulations .... ES-10[a]</td>
<td></td>
</tr>
<tr>
<td>ES9.2.1[a] Nominal Scenario Class Modeling Case............................. ES-11[a]</td>
<td></td>
</tr>
<tr>
<td>ES9.2.2[a] Early Failure Scenario Class Modeling Cases.................. ES-11[a]</td>
<td></td>
</tr>
<tr>
<td>ES9.2.3[a] Igneous Scenario Class Modeling Cases ......................... ES-12[a]</td>
<td></td>
</tr>
<tr>
<td>ES9.2.4[a] Seismic Scenario Class Modeling Cases .......................... ES-13[a]</td>
<td></td>
</tr>
<tr>
<td>ES9.2.5[a] Total Mean Annual Dose to the Reasonably Maximally Exposed Individual for the Repository System ................................................. ES-15[a]</td>
<td></td>
</tr>
</tbody>
</table>
## CONTENTS (Continued)

<table>
<thead>
<tr>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ES9.3[a]</td>
</tr>
<tr>
<td>ES9.3.1[a]</td>
</tr>
<tr>
<td>ES9.3.2[a]</td>
</tr>
<tr>
<td>ES9.4[a]</td>
</tr>
<tr>
<td>ES10[a]</td>
</tr>
</tbody>
</table>
# CONTENTS (Continued)

<table>
<thead>
<tr>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1[a]. PURPOSE</td>
</tr>
<tr>
<td>1.1[a] INTRODUCTION</td>
</tr>
<tr>
<td>1.1.1[a] Governing Regulations</td>
</tr>
<tr>
<td>1.1.2[a] Total System Performance Assessment Methodology</td>
</tr>
<tr>
<td>1.1.3[a] Treatment of Uncertainty</td>
</tr>
<tr>
<td>1.2[a] TSPA-LA MODEL DEVELOPMENT PROCESS</td>
</tr>
<tr>
<td>1.3[a] YUCCA MOUNTAIN SITE DESCRIPTION</td>
</tr>
<tr>
<td>1.4[a] DESIGN OF YUCCA MOUNTAIN REPOSITORY SUBSURFACE FACILITIES</td>
</tr>
<tr>
<td>1.5[a] GENERAL DESCRIPTION OF THE TSPA-LA MODEL</td>
</tr>
<tr>
<td>1.6[a] CONCEPTUAL DESCRIPTION OF PROCESSES RELEVANT TO AN EVALUATION OF POSTCLOSURE PERFORMANCE IN THE ABSENCE OF DISRUPTIVE EVENTS</td>
</tr>
<tr>
<td>1.7[a] CONCEPTUAL DESCRIPTION OF PROCESSES RELEVANT TO AN EVALUATION OF POSTCLOSURE PERFORMANCE AFTER THE OCCURRENCE OF DISRUPTIVE EVENTS</td>
</tr>
<tr>
<td>1.8[a] CONSERVATISMS AND LIMITATIONS RELATED TO THE TSPA-LA MODEL</td>
</tr>
<tr>
<td>1.8.1[a] Conservatisms Incorporated in the TSPA-LA Model</td>
</tr>
<tr>
<td>1.8.2[a] Limitations of the TSPA-LA Model</td>
</tr>
<tr>
<td>1.9[a] DESCRIPTION OF THE TOTAL SYSTEM PERFORMANCE ASSESSMENT MODEL/ANALYSIS FOR THE LICENSE APPLICATION</td>
</tr>
<tr>
<td>1.10[a] DOCUMENT ORGANIZATION</td>
</tr>
<tr>
<td>1.10.1[a] Volume I[a]</td>
</tr>
<tr>
<td>1.10.2[a] Volume II[a]</td>
</tr>
<tr>
<td>1.10.3[a] Volume III[a]</td>
</tr>
<tr>
<td>2[a]. QUALITY ASSURANCE</td>
</tr>
<tr>
<td>2.1[a] CONFIGURATION MANAGEMENT</td>
</tr>
<tr>
<td>3[a]. USE OF SOFTWARE</td>
</tr>
<tr>
<td>3.1[a] INTRODUCTION</td>
</tr>
<tr>
<td>3.2[a] ASHPLUME_DLL_LA</td>
</tr>
<tr>
<td>3.3[a] CWD</td>
</tr>
<tr>
<td>3.4[a] EXDOC_LA</td>
</tr>
<tr>
<td>3.5[a] FAR</td>
</tr>
<tr>
<td>3.6[a] FEHM</td>
</tr>
<tr>
<td>3.7[a] GETTHK_LA</td>
</tr>
<tr>
<td>3.8[a] GOLDSIM</td>
</tr>
<tr>
<td>3.8.1[a] Description of Software</td>
</tr>
<tr>
<td>3.8.2[a] Relationship to the TSPA-LA Model</td>
</tr>
</tbody>
</table>
## CONTENTS (Continued)

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.8.3[a] Software Documentation</td>
<td>3-2[a]</td>
</tr>
<tr>
<td>3.8.4[a] Range of Validation</td>
<td>3-2[a]</td>
</tr>
<tr>
<td>3.9[a] INTERPZDLL_LA</td>
<td>3-2[a]</td>
</tr>
<tr>
<td>3.10[a] MFCP_LA</td>
<td>3-2[a]</td>
</tr>
<tr>
<td>3.11[a] MKTABLE AND MKTABLE_LA</td>
<td>3-2[a]</td>
</tr>
<tr>
<td>3.12[a] MVIEW</td>
<td>3-2[a]</td>
</tr>
<tr>
<td>3.13[a] PASSTABLE1D_LA</td>
<td>3-3[a]</td>
</tr>
<tr>
<td>3.14[a] PASSTABLE3D_LA</td>
<td>3-3[a]</td>
</tr>
<tr>
<td>3.15[a] PREWAP_LA</td>
<td>3-3[a]</td>
</tr>
<tr>
<td>3.16[a] SCCD</td>
<td>3-3[a]</td>
</tr>
<tr>
<td>3.17[a] SEEPAGEDDLL_LA</td>
<td>3-3[a]</td>
</tr>
<tr>
<td>3.18[a] SOILEXP_LA</td>
<td>3-3[a]</td>
</tr>
<tr>
<td>3.19[a] SZ_CONVOLUTE</td>
<td>3-3[a]</td>
</tr>
<tr>
<td>3.20[a] TSPA_INPUT_DB</td>
<td>3-3[a]</td>
</tr>
<tr>
<td>3.21[a] WAPDEG</td>
<td>3-3[a]</td>
</tr>
<tr>
<td>3.22[a] CORROBORATIVE SOFTWARE USED</td>
<td>3-3[a]</td>
</tr>
<tr>
<td>4[a]. INPUTS</td>
<td></td>
</tr>
<tr>
<td>4.1[a] DIRECT INPUTS</td>
<td>4-1[a]</td>
</tr>
<tr>
<td>4.2[a] TSPA-LA MODEL-GENERATED PARAMETERS</td>
<td>4-1[a]</td>
</tr>
<tr>
<td>4.3[a] PARAMETER ENTRY FORMS</td>
<td>4-1[a]</td>
</tr>
<tr>
<td>4.4[a] TRACEABILITY OF INPUTS</td>
<td>4-1[a]</td>
</tr>
<tr>
<td>4.5[a] CRITERIA</td>
<td>4-1[a]</td>
</tr>
<tr>
<td>4.6[a] CODES AND STANDARDS</td>
<td>4-1[a]</td>
</tr>
<tr>
<td>4.7[a] TSPA INPUT DATABASE</td>
<td>4-1[a]</td>
</tr>
<tr>
<td>5[a]. ASSUMPTIONS</td>
<td></td>
</tr>
<tr>
<td>5.1[a] NOMINAL SCENARIO CLASS</td>
<td>5-1[a]</td>
</tr>
<tr>
<td>5.2[a] EARLY FAILURE SCENARIO CLASS</td>
<td>5-1[a]</td>
</tr>
<tr>
<td>5.3[a] IGNEOUS SCENARIO CLASS</td>
<td>5-1[a]</td>
</tr>
<tr>
<td>5.4[a] SEISMIC SCENARIO CLASS</td>
<td>5-1[a]</td>
</tr>
<tr>
<td>5.5[a] HUMAN INTRUSION SCENARIO</td>
<td>5-1[a]</td>
</tr>
<tr>
<td>6[a]. TSPA-LA MODEL DESCRIPTION</td>
<td></td>
</tr>
<tr>
<td>6.1[a] CONCEPTUAL DESIGN</td>
<td>6-1[a]</td>
</tr>
<tr>
<td>6.1.1[a] Features, Events, and Processes Screening and Scenario Development</td>
<td>6-1[a]</td>
</tr>
<tr>
<td>6.1.2[a] Calculation of Dose for the TSPA-LA Model</td>
<td>6-1[a]</td>
</tr>
<tr>
<td>6.1.3[a] Treatment of Uncertainty in the TSPA-LA Model</td>
<td>6-3[a]</td>
</tr>
<tr>
<td>6.1.4[a] TSPA-LA Model Structure and Design</td>
<td>6-3[a]</td>
</tr>
<tr>
<td>6.1.5[a] TSPA-LA Model File Architecture</td>
<td>6-7[a]</td>
</tr>
<tr>
<td>6.2[a] ALTERNATIVE CONCEPTUAL MODELS</td>
<td>6-13[a]</td>
</tr>
<tr>
<td>6.3[a] TSPA-LA MODEL FOR THE NOMINAL SCENARIO CLASS</td>
<td>6-13[a]</td>
</tr>
</tbody>
</table>

MDL-WIS-PA-000005 REV 00 AD 01 vi[a]  March 2008
## CONTENTS (Continued)

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.3.1[a]</td>
<td>Mountain-Scale Unsaturated Zone Flow</td>
<td>6-13[a]</td>
</tr>
<tr>
<td>6.3.2[a]</td>
<td>Engineered Barrier System Thermal-Hydrologic Environment</td>
<td>6-13[a]</td>
</tr>
<tr>
<td>6.3.3[a]</td>
<td>Drift-Scale Unsaturated Zone Flow</td>
<td>6-17[a]</td>
</tr>
<tr>
<td>6.3.4[a]</td>
<td>Engineered Barrier System Chemical Environment</td>
<td>6-17[a]</td>
</tr>
<tr>
<td>6.3.5[a]</td>
<td>Waste Package and Drip Shield Degradation</td>
<td>6-18[a]</td>
</tr>
<tr>
<td>6.3.6[a]</td>
<td>Engineered Barrier System Flow</td>
<td>6-19[a]</td>
</tr>
<tr>
<td>6.3.7[a]</td>
<td>Waste Form Degradation and Mobilization</td>
<td>6-23[a]</td>
</tr>
<tr>
<td>6.3.8[a]</td>
<td>Engineered Barrier System Transport</td>
<td>6-31[a]</td>
</tr>
<tr>
<td>6.3.9[a]</td>
<td>Unsaturated Zone Transport</td>
<td>6-35[a]</td>
</tr>
<tr>
<td>6.3.10[a]</td>
<td>Saturated Zone Flow and Transport Model Component</td>
<td>6-41[a]</td>
</tr>
<tr>
<td>6.3.11[a]</td>
<td>Biosphere</td>
<td>6-49[a]</td>
</tr>
<tr>
<td>6.4[a]</td>
<td>TSPA-LA MODEL FOR THE EARLY FAILURE SCENARIO CLASS</td>
<td>6-49[a]</td>
</tr>
<tr>
<td>6.5[a]</td>
<td>TSPA-LA MODEL FOR THE IGNEOUS SCENARIO CLASS</td>
<td>6-49[a]</td>
</tr>
<tr>
<td>6.6[a]</td>
<td>TSPA-LA MODEL FOR THE SEISMIC SCENARIO CLASS</td>
<td>6-49[a]</td>
</tr>
<tr>
<td>6.6.1[a]</td>
<td>TSPA-LA Model Components and Submodels for the Seismic Scenario Class</td>
<td>6-49[a]</td>
</tr>
<tr>
<td>6.6.2[a]</td>
<td>Interaction of Seismic Scenario Class Submodels with other TSPA-LA Submodels</td>
<td>6-53[a]</td>
</tr>
<tr>
<td>6.6.3[a]</td>
<td>Model Component Consistency and Conservatisms in Assumptions and Parameters</td>
<td>6-54[a]</td>
</tr>
<tr>
<td>6.6.4[a]</td>
<td>Alternative Conceptual Model(s) for Seismic Scenario Modeling Cases</td>
<td>6-54[a]</td>
</tr>
<tr>
<td>6.7[a]</td>
<td>TSPA-LA MODEL FOR THE HUMAN INTRUSION SCENARIO</td>
<td>6-59[a]</td>
</tr>
</tbody>
</table>

**MDL-WIS-PA-000005 REV 00 AD 01 vii[a] March 2008**
# FIGURES

<table>
<thead>
<tr>
<th>FIGURE</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ES-12[a]</td>
<td>Topographic Map of the Yucca Mountain Site Showing Differences in Slope Characteristics North and South of Drill Hole Wash</td>
</tr>
<tr>
<td>ES-40[a]</td>
<td>Total Expected Annual Dose for 10,000 Years after Repository Closure</td>
</tr>
<tr>
<td>ES-41[a]</td>
<td>Total Expected Annual Dose for 1,000,000 Years after Repository Closure</td>
</tr>
<tr>
<td>ES-42[a]</td>
<td>Contribution of Individual Radionuclides to Total Mean Annual Dose for 10,000 Years after Repository Closure</td>
</tr>
<tr>
<td>ES-43[a]</td>
<td>Contribution of Individual Radionuclides to Total Mean Annual Dose for 1,000,000 Years after Repository Closure</td>
</tr>
<tr>
<td>ES-44[a]</td>
<td>Annual Dose for the Nominal Scenario Class Modeling Case for the Post-10,000-Year Period</td>
</tr>
<tr>
<td>ES-45[a]</td>
<td>Mean Annual Dose Contributions from Major Radionuclides for the Nominal Scenario Class Modeling Case for the Post-10,000-Year Period</td>
</tr>
<tr>
<td>ES-46[a]</td>
<td>Expected Annual Dose for the Drip Shield Early Failure Modeling Case for (a) the First 10,000 Years after Repository Closure and (b) Post-10,000-Year Period</td>
</tr>
<tr>
<td>ES-47[a]</td>
<td>Mean Annual Dose Contributions from Major Radionuclides for the Drip Shield Early Failure Modeling Case for (a) the First 10,000 Years after Repository Closure and (b) Post-10,000-Year Period</td>
</tr>
<tr>
<td>ES-48[a]</td>
<td>Expected Annual Dose for the Waste Package Early Failure Modeling Case for (a) the First 10,000 Years after Repository Closure and (b) Post-10,000-Year Period</td>
</tr>
<tr>
<td>ES-49[a]</td>
<td>Mean Annual Dose Contributions from Major Radionuclides for the Waste Package Early Failure Modeling Case for (a) the First 10,000 Years after Repository Closure and (b) Post-10,000-Year Period</td>
</tr>
<tr>
<td>ES-50[a]</td>
<td>Expected Annual Dose for the Igneous Intrusion Modeling Case for (a) 10,000 Years after Repository Closure and (b) Post-10,000-Year Period</td>
</tr>
<tr>
<td>ES-51[a]</td>
<td>Mean Annual Dose Contributions from Major Radionuclides for the Igneous Intrusion Modeling Case for (a) the First 10,000 Years after Repository Closure and (b) Post-10,000-Year Period</td>
</tr>
<tr>
<td>ES-54[a]</td>
<td>Expected Annual Dose for the Seismic Ground Motion Modeling Case for (a) 10,000 Years after Repository Closure and (b) Post-10,000-Year Period</td>
</tr>
<tr>
<td>ES-55[a]</td>
<td>Mean Annual Dose Contributions from Major Radionuclides for the Seismic Ground Motion Modeling Case for (a) the First 10,000 Years after Repository Closure and (b) Post-10,000-Year Period</td>
</tr>
<tr>
<td>ES-56[a]</td>
<td>Expected Annual Dose for the Seismic Fault Displacement Modeling Case for (a) 10,000 Years after Repository Closure and (b) Post-10,000-Year Period</td>
</tr>
<tr>
<td>ES-57[a]</td>
<td>Mean Annual Dose Contributions from Major Radionuclides for the Seismic Fault Displacement Modeling Case for (a) 10,000 Years after Repository Closure and (b) Post-10,000-Year Period</td>
</tr>
</tbody>
</table>
**FIGURES (Continued)**

<table>
<thead>
<tr>
<th>FIGURE</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ES-58[a]</td>
<td>Total Mean Annual Dose and Median Annual Doses for Each Modeling Case for (a) 10,000 Years after Repository Closure and (b) Post-10,000-Year Period</td>
<td>FES-18[a]</td>
</tr>
<tr>
<td>ES-59[a]</td>
<td>Combined (^{226}\text{Ra}) and (^{228}\text{Ra}) Activity Concentrations, Excluding Natural Background, for Likely Features, Events, and Processes Using Nominal, Early Failure, and Seismic Ground Motion Damage Processes</td>
<td>FES-19[a]</td>
</tr>
<tr>
<td>ES-60[a]</td>
<td>Combined Activity Concentrations of All Alpha Emitters (including (^{226}\text{Ra}) but without radon and uranium isotopes), Excluding Natural Background, for Likely Features, Events, and Processes Using Nominal, Early Failure, and Seismic Ground Motion Damage Processes</td>
<td>FES-20[a]</td>
</tr>
<tr>
<td>ES-61[a]</td>
<td>Mean Annual Drinking Water Dose from Combined Beta and Photon Emitters for Likely Features, Events, and Processes using the Nominal, Early Failure, and Seismic Ground Motion Damage Processes</td>
<td>FES-21[a]</td>
</tr>
<tr>
<td>ES-62[a]</td>
<td>Expected Annual Individual Dose at the RMEI Location from a Human Intrusion 200,000 Years after Repository Closure</td>
<td>FES-22[a]</td>
</tr>
<tr>
<td>3-2[a]</td>
<td>TSPA-LA Software Architecture</td>
<td>3-9[a]</td>
</tr>
<tr>
<td>6.1.4-5[a]</td>
<td>Information Transfer between the Submodels of the TSPA-LA Volcanic Eruption Modeling Case</td>
<td>6-5[a]</td>
</tr>
<tr>
<td>6.3.2-7[a]</td>
<td>Repository Percolation Subregions Used in the TSPA-LA Model (based upon the 10th percentile infiltration scenario, glacial-transition period)</td>
<td>6-15[a]</td>
</tr>
<tr>
<td>6.3.6-3[a]</td>
<td>Illustrative Cross Section of a Typical Emplacement Drift</td>
<td>6-21[a]</td>
</tr>
<tr>
<td>6.3.10-8[a]</td>
<td>Radionuclide Decay Chains Considered in Saturated Zone Transport Calculations</td>
<td>6-47[a]</td>
</tr>
<tr>
<td>6.6-13[a]</td>
<td>Quadratic Fit for Mean Damaged Area on a CDSP WP under an Intact Drip Shield: (a) 23-mm WP Outer Barrier with Intact Internals, (b) 23-mm WP Outer Barrier with Degraded Internals, and (c) 17-mm WP Outer Barrier with Degraded Internals</td>
<td>6-57[a]</td>
</tr>
<tr>
<td>TABLES</td>
<td>Page</td>
<td></td>
</tr>
<tr>
<td>----------------------------------------------------------------------</td>
<td>------------</td>
<td></td>
</tr>
<tr>
<td>ES-1[a]. Top-Ranking Uncertainty Importance Parameters ..................</td>
<td>ES-16[a]</td>
<td></td>
</tr>
<tr>
<td>3-1[a]. TSPA-LA Model Software Codes .........................................</td>
<td>3-5[a]</td>
<td></td>
</tr>
<tr>
<td>3-8[a]. GoldSim Software Documents for Version 9.60.300 (STN: 10344-9.60-30)</td>
<td>3-7[a]</td>
<td></td>
</tr>
<tr>
<td>4-1[a]. Direct Inputs .....................................................................</td>
<td>4-3[a]</td>
<td></td>
</tr>
<tr>
<td>4-2[a]. Additional TSPA-LA Model Generated Data Tracking Numbers Referenced by Parameter Entry Forms</td>
<td>4-5[a]</td>
<td></td>
</tr>
<tr>
<td>6.1.5-1[a]. Location of Implementation Description in the GoldSim TSPA-LA Model File</td>
<td>6-9[a]</td>
<td></td>
</tr>
<tr>
<td>6.3.7-6[a]. Disposition of Radionuclides for Groundwater Release Modeling Cases: Nominal, Igneous Intrusion, and Seismic</td>
<td>6-25[a]</td>
<td></td>
</tr>
<tr>
<td>6.3.7-64[a]. Parameters for TSPA-LA Spent Nuclear Fuel Waste Form Reversible Colloid Abstraction</td>
<td>6-29[a]</td>
<td></td>
</tr>
<tr>
<td>6.3.8-4[a]. Sampled Model Inputs Used in the EBS Radionuclide Transport Abstraction</td>
<td>6-33[a]</td>
<td></td>
</tr>
<tr>
<td>6.3.9-1[a]. Radionuclide Half-Life and Daughter Products Used in the TSPA-LA Addendum</td>
<td>6-39[a]</td>
<td></td>
</tr>
<tr>
<td>6.3.10-8[a]. Radionuclide Species Mass Passed to the Biosphere Submodel</td>
<td>6-45[a]</td>
<td></td>
</tr>
<tr>
<td>6.6-3[a]. Seismic Ground Motion and Fault Displacement Modeling Cases Using Pre-Specified Parameters</td>
<td>6-55[a]</td>
<td></td>
</tr>
</tbody>
</table>
EXECUTIVE SUMMARY

This addendum to the Executive Summary in Total System Performance Assessment Model/Analysis for the License Application (hereafter referred to as the parent document), contains changes in the form of corrections and insertions for clarity. The addendum to the Executive Summary consists of a combination of supplemental information and revised TSPA-LA Model results for the postclosure performance demonstrations in revisions to plots, tables, and discussions found in the parent document. The organization of the sections and subsections is the same as found in the parent document. Section, figure, and table numbers referred to in the text with [a] indicate sections of this addendum with revised information, while those without [a] refer to the unrevised section, figure, and table numbers in the parent document. Each section designated as no change means the reader should refer to the parent document for the content of that section. In some cases, portions of the Executive Summary are restated from the parent document for clarity. This addendum to the Executive Summary is intended to be used in conjunction with the Executive Summary in the parent document.

ES1[a] SCOPE

This addendum provides minor corrections as well as an update of the results of the Total System Performance Assessment for the License Application (TSPA-LA) presented in Total System Performance Assessment Model/Analysis for the License Application. The updated TSPA-LA Model results address the issues identified and described in Appendix P of the parent document. The issues were identified during analysis, checking, and review activities. These issues, documented in Appendix P of the parent document, were primarily related to minor inaccuracies in model implementation and identification of undocumented or unintended conservatisms or non-conservatisms. TSPA-LA Model v5.005 incorporates changes to TSPA-LA Model v5.000, the source for results in the parent document, and TSPA-LA Model v5.005 was used to provide the analyses presented in this addendum. Appendix P[a] of this addendum includes tables that summarize the issues that were addressed in the development of TSPA-LA Model v5.005. Tables P-6[a] and P-7[a] discuss the changes to TSPA-LA Model v5.005 in response to the issues identified in Appendix P of the parent document. Table P-6[a] summarizes the TSPA-LA Model implementation issues and Table P-7[a] summarizes the impact assessments as a result of the changes to the TSPA-LA Model. The additional analyses presented in this addendum were developed according to the review criteria outlined in Technical Work Plan for: Total System Performance Assessment FY 07-08 Activities (SNL 2008 [DIRS 184920], Sections 2.1.4 and 2.3.5.2.1).

ES1.1[a] Introduction

The performance requirements discussed in Section ES1.1[a] are restated from the parent document in order to provide clarity in the subsequent presentation.

Among the regulatory mandates of U.S. Nuclear Regulatory Commission (NRC) Proposed Rule 10 CFR Part 63 ([DIRS 178394] and [DIRS 180319]) is the requirement to demonstrate, by means of a probabilistic assessment, that there is a reasonable expectation of meeting the requirements of 10 CFR 63 Subpart L (DIRS 180319) regarding waste isolation after closure of the repository (NRC Proposed Rule 10 CFR 63.303, unrevised, [DIRS 180319]) according to the
performance measures given in NRC Proposed Rule 10 CFR 63.303(a) and (b) [DIRS 178394]. NRC Proposed Rule 10 CFR Part 63 ([DIRS 178394] and [DIRS 180319]) sets standards for individual protection and for protection of groundwater. The Individual Protection Standard after Permanent Closure applies to the first 10,000 years following repository closure (10 CFR 63.311(a)(1) [DIRS 178394]), and 10 CFR 63.311(a)(2) [DIRS 178394] specifies the individual protection standard from 10,000 years to the period of geologic stability, defined as one million years after disposal (10 CFR 63.302 [DIRS 178394]).

Figure ES-1 shows the Yucca Mountain area and the entrance to the underground facilities, which will become part of the repository after a license to construct the repository is granted. Figure ES-2 shows a timeline of the major legislative and regulatory actions bearing on the Yucca Mountain Project from 1980 to the present.

In particular, the TSPA-LA Model calculates estimates of the:

a. Annual doses to the reasonably maximally exposed individual (RMEI) from releases from the undisturbed Yucca Mountain disposal system (NRC Proposed Rule 10 CFR 63.311 [DIRS 178394], Individual Protection Standard after Permanent Closure), subject to the performance measures in NRC Proposed Rule 10 CFR 63.303 [DIRS 178394]

b. Annual doses to the RMEI from releases from the Yucca Mountain disposal system resulting from human intrusion (NRC Proposed Rule 10 CFR 63.321 [DIRS 178394], Individual Protection Standard for Human Intrusion), excluding very low probability events after 10,000 years per NRC Proposed Rule 10 CFR 63.342(b) [DIRS 178394]

c. Levels of radioactivity (NRC Proposed Rule 10 CFR 63.331 [DIRS 180319], Separate Standards for Protection of Groundwater) in the representative annual volume of groundwater of 3,000 acre-feet (NRC Proposed Rule 10 CFR 63.332(a)(3) [DIRS 180319])

d. Annual doses to the RMEI for early drip shield (DS) and waste package (WP) failures, the two failure modes that meet the low probability of occurrence requirement of NRC Proposed Rule 10 CFR 63.342(a) [DIRS 178394]

e. Mean annual doses to the RMEI for all scenario classes considered for 10,000 years after repository closure (NRC Proposed Rule 10 CFR 63.342(c)(1) [DIRS 178394])

f. Median annual doses to the RMEI for all scenario classes considered (NRC Proposed Rule 10 CFR 63.342(c)(1) [DIRS 178394]) after 10,000 years but within the period of geologic stability.

**ES2[a]** TOTAL SYSTEM PERFORMANCE ASSESSMENT METHODOLOGY

The general TSPA process adopted by the U.S. Department of Energy (DOE) follows the methodology described by the NRC (Eisenberg et al. 1999 [DIRS 155354], Section 1 and Appendix A). Over time, the methodology has been developed and enhanced by critical reviews
Total System Performance Assessment Model/Analysis for the License Application

No change.

ES3.1[a] Features, Events, and Processes Analysis

No change.

ES3.2[a] Development of the Scenario Classes

The TSPA-LA approach focuses on a set of scenario classes that are distinguished by initiating events. The Nominal Scenario Class includes all possible future outcomes except those initiated by early failure of the DSs or WPs, igneous or seismic activity, and inadvertent human intrusion into the repository. The Early Failure Scenario Class addresses FEPs that describe the potential for DS and WP early failure in the absence of igneous or seismic events. The early failure scenarios include DSs and WPs that fail prematurely. The Igneous Scenario Class includes all possible future outcomes initiated by igneous activity. The Seismic Scenario Class includes all possible future outcomes initiated by seismic activity. In addition to the analyses of the scenario classes, the TSPA-LA Model also simulates a Human Intrusion Scenario according to the scenario description and criteria in 10 CFR 63.322 [DIRS 180319].

ES3.3[a] Incorporation of Uncertainty

No change.
ES3.4[a]  Natural and Engineered Model Components
No change.

ES3.5[a]  Alternative Conceptual Models
No change.

ES3.6[a]  Configuration Management for the TSPA-LA Model
No change.

ES4[a]  YUCCA MOUNTAIN SITE DESCRIPTION
No change.

ES4.1[a]  Physiographic Setting and Topography
There is no change to the text of ES4.1. However, the caption for Figure ES-12 in the parent document has been corrected and is included as Figure ES-12[a] of this addendum.

ES4.2[a]  Climate
No change

ES4.3[a]  Geology
No change.

ES4.4[a]  Regional Tectonic Setting
The overall tectonic setting of the Great Basin physiographic province, including Yucca Mountain, is extensional, and generally consisting of fault-bounded basins and mountain ranges that have been modified by volcanic activity during the past 15 million years. Typically, the faults in the Great Basin include normal and strike-slip faults that reflect the extensional deformation caused by plate tectonic interactions in the western portion of the North American continent. The structural geology of Yucca Mountain and its vicinity is generally characterized by north-trending normal faults with displacement down to the west (Figures ES-14 and ES-15). Some of the faults on Figure ES-14 show evidence of Quaternary activity (i.e., activity within the last 1.8 million years).

ES5[a]  THE REPOSITORY SUBSURFACE FACILITY AND ENGINEERED BARRIER SYSTEM
No change.

ES6[a]  NATURAL AND ENGINEERED BARRIERS
No change.
ES7[a]  GENERAL DESCRIPTION OF THE TSPA-LA MODEL

No change.

ES8[a]  VERIFICATION/VALIDATION OF THE TOTAL SYSTEM PERFORMANCE ASSESSMENT MODEL

SCI-PRO-006, *Models*, Section 6.3, was utilized to support verification and validation of the TSPA-LA Model, providing confidence that the TSPA-LA Model adequately represents the physical processes in the repository system and properly transfers outputs between the TSPA-LA Model modules and submodels. In preparing this addendum, each validation activity utilized for TSPA-LA Model v5.000 was reviewed to determine which activities were affected by changes made between TSPA-LA Model v5.000 and v5.005. Where validation activities could potentially be affected by these model changes, the affected validation activities were repeated using v5.005 to verify that model changes did not adversely affect the overall validation of the TSPA-LA Model. Additional verification and validation results beyond those presented in the parent document are also provided to further enhance confidence in the TSPA-LA Model. This section summarizes revised or additional validation activities that were conducted for TSPA-LA Model v5.005 and are documented in this addendum. The following subsections include any changes to the Executive Summary in the parent document.

ES8.1[a]  Verification and Validation Strategy

No change.

ES8.2[a]  Computer Code and Input Verification

The following model verification activities are described in the parent document and/or were revised and included in this addendum and demonstrate that incorporation of information and submodels from other sources into the TSPA-LA Model has not altered the validity of the information, the submodels, or both:

- The TSPA-LA Model software, GoldSim, was qualified and placed under the control of Software Configuration Management per IM-PRO-003.
- Outputs from DLLs from other sources, including analysis/model reports and data tracking numbers, were correctly replicated in the TSPA-LA Model.
- Analysis of the verification of the range of applicability of submodels and model components was performed.
- Outputs from DLLs calculated within the TSPA-LA Model were found to be within established acceptance criteria.
- Individual submodels were validated in their respective analysis/model reports.
- Results from submodels within the TSPA-LA Model were compared to results contained in analysis/model reports and were found to agree within selected acceptance criteria.
Feeds from one submodel to another submodel were found to be correctly transferred, and the values used were determined to be appropriate for the intended use of the receiving submodel (Section 7.2.6[a]).

Inputs from the TSPA Input Database were verified to correspond with source data.

Computer codes and input reverification presented in Section 7.2[a] include: (1) reverification of a revised version of the GoldSim software (GoldSim V9.60.300, STN: 10344-9.60-03 [DIRS 184387]) used in all updated TSPA-LA Model results reported in this addendum; (2) verification testing for the Human Intrusion Submodel, testing that was inadvertently omitted from the parent document (Section 7.2.4.1.12[a]); and (3) a summary of an assessment of the range of validity for all TSPA-LA Model submodels that was inadvertently omitted from the parent document (Section 7.2.6[a]).

The activities in Section 7.2 of the parent document and the additional work presented in Section 7.2[a] of this addendum demonstrate that the system software for TSPA-LA Model v5.005 is appropriate and valid, that input is correct and verified, that the internal transfer of information within TSPA-LA Model v5.005 is correct and within the valid range of successive submodels, and that submodels are valid per their respective source analysis/model reports. Therefore, incorporation of information and submodels from other sources into TSPA-LA Model v5.005 has not altered the validity of the information or the submodels, or both, as demonstrated in the parent document for TSPA-LA Model v5.000.

ES8.3[a] Stability Testing

Section 7.3.1 of the parent document presents analyses that demonstrate the statistical stability of the total mean annual dose (summed over all modeling cases) and the mean annual dose for each modeling case for TSPA-LA Model v5.000. Section 7.3.1[a] compares uncertainty and sensitivity analyses generated by TSPA-LA Model v5.000 and TSPA-LA Model v5.005 and concludes that the results from TSPA-LA Model v5.005 are also statistically stable. An additional illustration of the stability of the estimate of the total mean annual dose for TSPA-LA Model v5.005, using a bootstrap sampling procedure to generate confidence intervals, is presented for results for both the 10,000-year and 1,000,000-year time periods. This addendum confirms the numerical accuracy of the expected annual dose calculations for the Seismic Fault Displacement Modeling Case.

This addendum also includes an update to the evaluation of temporal stability of the TSPA-LA Model for both the Nominal Modeling Case and the Human Intrusion Modeling Case. A reevaluation of the temporal stability of the Human Intrusion Modeling Case was necessary due to the change in the timestepping system used for the Human Intrusion Modeling Case in TSPA-LA Model v5.005. The simulations were conducted by reducing the TSPA-LA Model timestep size to examine sensitivity to timestep duration. The annual dose from the TSPA-LA Model calculations with different timestep durations were compared graphically to determine the effect of changing the timestep durations. The approach and results of this analysis are provided in Section 7.3.3 of the parent document. The results of this analysis show a better resolution using the revised timestep durations than previously documented in the parent document. The
test results for the Human Intrusion Modeling Case confirm that its timestep system was adequate.

Section 7.3.3.7[a] presents a revised evaluation of the temporal stability of the TSPA-LA Model Nominal Modeling Case. The temporal discretization used to determine general corrosion rates is influential to the annual dose resulting from nominal corrosion processes. The nominal modeling case simulation was conducted with shorter timesteps for the calculation of the crack growth rate, which removes the jumps in the number of WP failures by stress corrosion cracking (SCC), which in turn is reflected in the expected annual dose curves for the alternative timestepping. However, the similarity in statistics for expected annual dose for the two timestep durations indicates that the Nominal Modeling Case is sufficiently stable with respect to temporal discretization.

Section 7.3.2[a] demonstrates that the calculation of expected annual dose is sufficiently accurate for each TSPA-LA Model modeling case.

**ES8.4[a] Uncertainty Characterization Reviews**

No change.

**ES8.5[a] Surrogate Waste Form Validation**

Section 7.5.3[a] presents a reevaluation of the adequacy of using commercial spent nuclear fuel (CSNF) as a surrogate for naval spent nuclear fuel (NSNF) using TSPA-LA Model v5.005. The analyses presented in Section 7.5 of the parent document and Section 7.5[a] of this addendum show that the use of a surrogate to represent NSNF is appropriate. The analyses show that mean annual dose from NSNF is bounded by the mean annual dose calculated for the Zircaloy-clad CSNF surrogate.

**ES8.6[a] Corroboration of Abstraction Model Results with Validated Process Models**

No change.

**ES8.7[a] Auxiliary Analyses**

The auxiliary analyses presented in the parent document were updated with a reevaluation of the corroboration of the TSPA-LA Model results documented in the parent document with auxiliary analyses (Section 7.7[a]). These additional verification and validation activities further enhance confidence in the TSPA-LA Model.

**Single-Realization Analyses**

The single realization analyses presented in the parent document and in Section 7.7.1[a] comprise a comprehensive explanation of how the transport of key radionuclides is affected by coupling various submodel components of the engineered barrier system (EBS), unsaturated zone (ÜZ), and saturated zone (SZ) domains in the TSPA-LA Model, following WP failure under varying physical-chemical-thermal-mechanical conditions. These results provide confidence that these model components are working as expected and the aggregate TSPA-LA
Model results (in terms of dose) are consistent with the model components. Examination and explanation of key aspects affecting radionuclide releases demonstrate that the TSPA-LA Model is functioning as intended and that the submodels are coupled correctly and provide system-level results. The revised analyses in this addendum provide confidence that TSPA-LA Model v5.005 is functioning as designed and helps confirm the validation of the model.

The parent document includes single realization analyses of four modeling cases: (1) Waste Package EF Modeling Case, (2) Drip Shield EF Modeling Case, (3) Igneous Intrusion Modeling Case, and (4) Seismic Ground Motion (GM) Modeling Case (1,000,000 years). The revised analyses using TSPA-LA Model v5.005 include additional analyses of outlier realizations in Section 7.7.1[a]. Three additional modeling cases: (1) Nominal Modeling Case, (2) Human Intrusion Modeling Case, and (3) Seismic GM Modeling Case (10,000 years), are included in this addendum. The results confirm that the changes from TSPA-LA Model v5.000 to TSPA-LA Model v5.005 support the demonstration of model validation and add to the confidence in the TSPA-LA Model results.

Comparison with Simplified TSPA Analysis

A comparison of the TSPA-LA Model results to a stand-alone Simplified TSPA Analysis was conducted and documented in Section 7.7.2 and Appendix L of the parent document. Section 7.7.2 of the parent document provides the comparative results for the individual modeling cases for the Simplified TSPA Analysis and the TSPA-LA Model, including the minor differences in the prominence of certain radionuclides and in the mean annual doses calculated by the two approaches. Section 7.7.2[a] provides a comparison of the updated results presented in this addendum with the Simplified TSPA Analysis in the parent document.

Section 7.7.2[a] compares the TSPA-LA Model v5.005 results to the Simplified TSPA Analysis and corroborates the conclusions presented in the parent document.

Comparison with Electric Power Research Institute TSPA Analysis

This addendum describes a limited comparison of the Electric Power Research Institute (EPRI) TSPA Analysis results with those of TSPA-LA Model v5.005. The similarities and differences between the EPRI TSPA Analysis and TSPA-LA Model v5.000 are discussed in Section 7.7.3 of the parent document. Appendix M of the parent document provides additional information.

The results documented in Section 7.7.3[a] confirm the general similarities as well as the differences between the results from the EPRI TSPA Analysis and those of the TSPA-LA Model as described in Section 7.7.3 of the parent document.

Performance Margin Analysis

A comparison of TSPA-LA Model v5.005 results with the Performance Margin Analysis (PMA) confirms the quantitative evaluation of the differences in repository performance due to significant explicit and implicit conservatisms embedded in the TSPA-LA Model subcomponents as documented in Section 7.7.4 and Appendix C of the parent document. The conservatisms were evaluated to (1) confirm that they are conservative with respect to the mean annual dose calculated by the TSPA-LA Model; (2) quantify the extent to which TSPA-LA Model v5.005
and the PMA, individually and collectively, overestimate the projected annual dose; and (3) assess whether or not the evaluated conservatisms introduced any inappropriate risk dilution in the TSPA-LA Model results presented in support of the LA. Section 7.7.4 of the parent document describes the approach and results of the PMA, and Appendix C provides additional supporting material. The results show that the margin evaluated in the PMA, as documented in the parent document, is indeed conservative with respect to the total system performance measures (e.g., maximum mean annual dose); the largest doses calculated in the PMA for 10,000 years and 1,000,000 years are lower than the doses used in the compliance demonstration presented in Section 8[a] of this addendum. The additional analyses confirm that the largest calculated PMA mean annual doses are lower by over an order of magnitude and a factor of two over the largest mean annual dose relative to the TSPA-LA Model (Section 8[a]) for the time periods of 10,000 years and 1,000,000 years, respectively. Further, this PMA confirms that the significant conservatisms did not introduce risk dilution in the TSPA-LA results, as demonstrated by the absence of higher maximum mean annual doses in the comparison of the projected total mean annual dose for the PMA relative to TSPA-LA Model v5.005. The differences in the relative contributions to the total mean annual dose from each of the modeling cases evaluated with the PMA and the TSPA-LA Model indicate that having fewer conservative assumptions in the PMA than in these TSPA-LA model components provides a performance margin in the projected annual dose predictions presented in Section 8 of the parent document and Section 8[a] of this addendum.

**ES8.8[a]  Confidence Building: Natural Analogues**

No change.

**ES8.9[a]  Summary of Technical Reviews**

Technical reviews of PA models form an important part of model validation. During the past decade, the Yucca Mountain Project has developed successive TSPA models as well as accompanying input process models, all of which have been subject to technical reviews by external experts as part of their validation. Each milestone PA for the Yucca Mountain repository was subject to external reviews. The Total System Performance Assessment for the Viability Assessment was the subject of a peer review as described in Section 7.9.1. An International Review Team conducted an evaluation of the TSPA-SR, and the accompanying TSPA-SR performance assessment model. Appendix E summarizes the 27 comments provided by the International Review Team review of the TSPA-SR Model. The responses to those comments were addressed and implemented as appropriate into the TSPA-LA Model and its supporting documents. An Independent Validation Review Team (IVRT) reviewed a draft version of the TSPA-LA Model and the accompanying IVRT report provided comments as described in Section 7.9. The comments from the IVRT technical review of the draft TSPA-LA Model were addressed, and the TSPA-LA Model incorporates the material contained in the responses to those comments.

**ES9[a]  SYSTEM PERFORMANCE ANALYSES**

The revisions found in the following subsections of Section ES9[a] contain primarily references to updated figures and revised estimates for the magnitude and timing of estimates of the
maximum mean annual dose, radionuclides of importance, revised results of the uncertainty/sensitivity analyses, and other information derived from the revised simulations of modeling cases using TSPA-LA Model v5.005. Except for one correction to a reference to proposed 10 CFR Part 63 and clarification of the language relating to meeting the proposed 10 CFR Part 63 performance standards, the text in this section is largely the same as that in the parent document.

The TSPA-LA Model was used to conduct a PA of the Yucca Mountain repository system. The analyses provide mean and median annual dose to the RMEI for the first 10,000 years after repository closure and for the period of geologic stability (one million years) specified in NRC Proposed Rule 10 CFR 63.302 [DIRS 178394]. The TSPA-LA Model evaluated modeling cases representing nominal conditions, early DS and WP failures, and disruptive events. The TSPA-LA Model analyses also address both the individual and groundwater protection standards of NRC Proposed Rule 10 CFR 63.311 [DIRS 178394] and 10 CFR 63.331 ([DIRS 180319], Table 1), respectively.

The analyses account for uncertainties in the representations of FEPs that could affect the annual dose. The PA analyses address the effect of alternative parameters, submodels, and approaches to FEPs. The calculations are probabilistic in the sense that the results are for multiple realizations, carried out using sampled values from the probability distributions for the values of the uncertain model parameters.

**ES9.1[a]** Total Mean Annual Dose to the Reasonably Maximally Exposed Individual for the Repository System

Figure ES-40[a] displays the total expected annual dose for the first 10,000 years after repository closure, and the calculated results indicate that the greatest mean annual dose for this period is less than 0.24 millirem. Figure ES-41[a] displays the total expected annual dose for the postclosure period from 10,000 to one million years after repository closure, and the calculated results indicate that the greatest median annual dose for this period is less than 0.96 millirem. These total expected annual dose values represent the sum of the expected dose calculations for the four scenario classes considered for the TSPA-LA Model. Figures ES-40[a] and ES-41[a] show the distribution of the expected annual doses and, thus, display the uncertainty in the total expected annual dose resulting from epistemic uncertainty about the repository system.

Figure ES-42[a] shows the radionuclides that contribute most to the estimate of mean annual dose, and indicates that $^{99}$Tc, $^{14}$C, $^{129}$I, and $^{239}$Pu dominate the estimated mean annual dose during the first 10,000 years after repository closure. In a similar manner, Figure ES-43[a] shows that $^{239}$Pu, $^{99}$Tc, and $^{129}$I generally dominate the mean annual dose for the first 100,000 years of the postclosure period, and that $^{242}$Pu, $^{237}$Np, $^{129}$I, and $^{226}$Ra generally dominate the mean annual dose for the postclosure period from 100,000 to one million years.

**ES9.2[a]** Results of the Scenario Class Modeling Case Simulations

Following are descriptions of the results provided by the scenario class modeling cases used to simulate repository performance. Figures ES-44[a] through ES-51[a] and ES-54[a] through ES-57[a] present the expected annual dose calculated for the individual modeling cases. Figures ES-52 and ES-53 for the Volcanic Eruption Modeling Case are unchanged from those in...
the parent document. The following sections describe, by modeling case, the results of the scenario class modeling case simulations.

**ES9.2.1[a] Nominal Scenario Class Modeling Case**

The results of this modeling case show no annual dose to the RMEI in the first 10,000 years. The earliest occurrence of dose is around 21,000 years. The projections of WP breaches exhibit a few realizations with a SCC crack penetrating the WP outer barrier well before 100,000 years. In particular, one crack penetration occurred in less than 10,000 years in one WP in one realization because a combination of sampled values for SCC in the closure-lid weld resulted in a large initial crack length and a high crack propagation velocity (Section 8.2.1). Because infiltration rates and temperatures vary across the repository footprint, the time of occurrence of the continuous thin film of adsorbed water required to begin diffusive radionuclide transport also varies, delaying radionuclide releases until after 10,000 years. The bulk of the WP failures (by nominal SCC) would occur after 100,000 years, and the DSs would begin to fail by general corrosion at approximately 260,000 years. Figure ES-44[a] shows the estimated maximum mean and median annual doses for the postclosure period from 10,000 to one million years, and the calculated results indicate that the values would be 0.55 and 0.28 millirem, respectively. Figure ES-45[a] shows the radionuclides that dominate the estimate of mean annual dose for the Nominal Scenario Class Modeling Case. The main contributors to mean annual dose would be the highly soluble and mobile radionuclides $^{129}$I and $^{99}$Tc.

**ES9.2.2[a] Early Failure Scenario Class Modeling Cases**

The Early Failure Scenario Class Modeling Cases include FEPs that relate to early WP and DS failure due to manufacturing, material defects, or pre-emplacement operations that would include improper heat treatment. Radionuclide mobilization and transport for the Early Failure Scenario Class is similar to the Nominal Scenario Class, but differs from the Nominal Scenario Class in that the Early Failure Scenario Class considers only WPs affected by early DS and WP failures.

**ES9.2.2.1[a] Drip Shield Early Failure Modeling Case**

The defective DSs were modeled as being failed at the time of repository closure, and WPs underlying any failed DSs and exposed to seepage are conservatively considered as failed. Figure ES-46[a] shows the expected annual dose histories for the first 10,000 years after closure and the postclosure period from 10,000 to one million years. The expected annual doses account for aleatory uncertainty about the number of early failed DSs, types of WPs under failed DSs, and their locations in the repository. The mean, median, and 5th and 95th percentile curves in this plot show the uncertainty in the expected annual dose due to epistemic uncertainty from incomplete knowledge of the behavior of the repository system. The calculations for the first 10,000 years indicate a projected mean annual dose of approximately $2.8 \times 10^{-4}$ millirem at 2,000 years after repository closure. The calculated mean annual dose then decreases steadily and is less than $1.5 \times 10^{-4}$ millirem during the postclosure period from 10,000 to one million years.

Figure ES-47a[a] shows that the radionuclides contributing most to the total mean annual dose during the first 2,000 years after repository closure are soluble and mobile radionuclides, in
particular $^{99}$Tc, $^{129}$I, and $^{14}$C. During the postclosure period from 10,000 to one million years, Figure ES-47b[a] shows that $^{239}$Pu dominated the mean annual dose for the first 200,000 years, and $^{242}$Pu and $^{237}$Np dominate the mean annual dose up to one million years.

**ES9.2.2[a] Waste Package Early Failure Modeling Case**

The WPs are assumed to be failed at the time of repository closure. However, intact DSs overlying early failed WPs will degrade by general corrosion after repository closure. Figure ES-48[a] shows the expected annual dose histories for the first 10,000 years after repository closure and for the postclosure period from 10,000 to one million years. The expected annual dose accounts for aleatory uncertainty about the number of early failed WPs, types of early failed WPs, and their locations in the repository. The mean, median, and 5th and 95th percentile curves on Figures ES-48a[a] and ES-48b[a] reflect the epistemic uncertainty in the expected annual dose.

Figure ES-48a[a] shows the estimated mean annual dose. The maximum mean annual dose occurs between 9,000 and 10,000 years and its value is $3.7 \times 10^{-3}$ millirem. The mean annual dose during the first 10,000 years postclosure results from early failed co-disposed (CDSP) WPs. The relative humidity in the CDSP WP emplacement locations tend to be higher and forms an aqueous layer suitable for radionuclide diffusion earlier than in the CSNF WPs. Because the CDSP WPs contain DOE SNF and the TSPA-LA Model does not take credit for the canister, cladding, or fuel matrix, diffusive transport of radionuclides can start as soon as the humidity in the breached CDSP WPs is greater than 95 percent (Section 8.2.2.2). The increase in mean annual dose at about 9,800 years postclosure, as shown on Figure ES-48a[a], is due to the beginning of diffusive transport from early-failed CSNF WPs. Figure ES-48b[a] shows the estimated mean and median annual doses; the calculated results indicate that the maximum values are $2.1 \times 10^{-2}$ and $6.1 \times 10^{-3}$ millirem, respectively, before 15,000 years, and the doses gradually decrease thereafter until about 250,000 years postclosure. At about 250,000 years postclosure, the DSs begin to fail from general corrosion, and the expected annual dose increases during the period from 300,000 to 400,000 years postclosure because of advective transport of radionuclides through failed WPs.

Figure ES-49a[a] shows that in the first 10,000 years after closure, the more soluble and mobile radionuclides, $^{99}$Tc, $^{129}$I, and $^{14}$C, dominate the estimate of mean annual dose. Figure ES-49b[a] shows that during the postclosure period from 10,000 to one million years, $^{239}$Pu, $^{242}$Pu, $^{237}$Np, and $^{226}$Ra dominate the expected mean annual dose.

**ES9.2.3[a] Igneous Scenario Class Modeling Cases**

The Igneous Scenario Class addresses the set of FEPs that describe igneous events that could affect repository performance. The Igneous Scenario Class is represented by: (1) the Igneous Intrusion Modeling Case that represents a magmatic dike that intrudes into the repository causing subsequent release of radionuclides to the groundwater in the UZ, and (2) the Volcanic Eruption Modeling Case that represents a hypothetical volcanic eruption from a volcanic conduit that passes through the repository and emerges at the land surface with the release of radionuclides to the atmosphere.
ES9.2.3.1[a] Igneous Intrusion Modeling Case

After a magmatic dike intersects the repository, radionuclide release and transport away from the repository would be similar to the Nominal Modeling Case. All of the DSs and WPs would be damaged, exposing the waste forms to percolating groundwater with subsequent degradation, radionuclide mobilization, and transport through the UZ to the SZ. The Igneous Intrusion Modeling Case considers that the remnants of the DSs, WPs, or cladding do not divert any water from the waste.

Figure ES-50[a] shows the distribution of calculated expected annual dose histories, one for each sample element, where each dose history accounts for aleatory uncertainty in igneous intrusions, such as the number of future events and the time at which they may occur. The mean, median, and 5th and 95th percentile curves on Figure ES-50[a] indicate epistemic uncertainty in expected annual dose resulting from incomplete knowledge of the behavior of the physical system during and after the disruptive event. The maximum calculated mean annual dose for the first 10,000 years postclosure is $6.6 \times 10^{-2}$ millirem, occurring at the end of the 10,000-year period. The maximum projected median annual dose during the postclosure period from 10,000 to one million years is estimated to be 0.32 millirem, and the maximum value occurs at the end of the one-million year period.

Figure ES-51a[a] shows that $^{99}$Tc and $^{129}$I dominate the estimate of the expected mean annual dose for the first 4,000 years, and $^{239}$Pu, $^{99}$Tc, and $^{240}$Pu dominate the estimate of the mean annual dose for the first 10,000 years postclosure. Figure ES-51b[a] shows that $^{239}$Pu dominates the estimate of the mean annual dose for the first 100,000 years, and $^{242}$Pu, $^{226}$Ra, and $^{237}$Np dominate the expected mean annual dose for the postclosure period from 10,000 to one million years.

ES9.2.3.2[a] Volcanic Eruption Modeling Case

No change.

ES9.2.4[a] Seismic Scenario Class Modeling Cases

The Seismic Scenario Class represents the direct effects of vibratory ground motion and fault displacement associated with seismic activity affecting repository performance. The Seismic Scenario Class modeling cases include seismic-related changes in seepage, the performance of WPs and DSs, and flow in the EBS. The Seismic Scenario Class is represented by the Seismic GM Modeling Case and the Seismic Fault Displacement (FD) Modeling Case.

ES9.2.4.1[a] Seismic Ground Motion Modeling Case

The Seismic GM Modeling Case considers the possible failures of DSs and WPs due to mechanical damage associated with seismic vibratory ground motion, including: accumulation of rockfall on DSs, collapse of the DS framework, SCC of WPs, and rupture or puncture of WPs. Figure ES-54[a] presents calculated expected annual dose histories for the Seismic GM Modeling Case for the first 10,000 years after closure and the postclosure period from 10,000 to one million years. The distribution of the expected annual dose takes into account aleatory
uncertainty associated with the number of seismic ground motion events, the time and magnitude of each event, and the effects of each event on WPs, DSs, and the emplacement drifts.

The mean, median, and 5th and 95th percentiles of the distribution of the expected annual dose shown on Figure ES-54[a] reflect epistemic uncertainty due to incomplete knowledge of the behavior of the repository system during and after seismic events. Figure ES-54[a] shows the mean annual dose for the first 10,000 years after closure, and the calculated results indicate that the maximum value is 0.17 millirem. The maximum median annual dose for the postclosure period from 10,000 to one million years was calculated to be 0.37 millirem. The plot of the expected annual doses shown on Figure ES-54[a] was developed using a quadrature method to numerically integrate over the aleatory uncertainty for the first 10,000 years after repository closure. Alternatively, the realizations contributing to Figure ES-54b[a] were calculated using a Monte Carlo method to numerically integrate over aleatory uncertainty for the postclosure period from 10,000 to one million years.

The results on Figure ES-55[a] show that $^{99}$Tc, $^{14}$C, $^{129}$I, and $^{36}$Cl dominate the estimate of the mean for the first 10,000 years after closure. Figure ES-55b[a] shows that radionuclides $^{99}$Tc, $^{129}$I, $^{242}$Pu, and $^{237}$Np dominate the calculated expected mean annual dose during most of the postclosure period from 100,000 to one million years, with $^{242}$Pu and $^{237}$Np increasingly prominent after 800,000 years postclosure. Because of radioactive decay, the expected mean annual dose due to $^{14}$C decreases to insignificant levels within the first 100,000 years postclosure. The CDSP WPs would be the primary WPs damaged during the first 10,000 years after closure because the CSNF WPs are more failure resistant. The CSNF WPs will be more robust than CDSP WPs because they include two inner stainless-steel vessels instead of one. Although the CSNF WPs have an inner vessel and lid similar to the CDSP WPs, the CSNF WPs are placed in an outer, tightly fitting stainless-steel transportation, aging, and disposal canister. In contrast, the CDSP WPs contain several smaller waste-containing canisters that do not fit as tightly and could move more freely under the influence of ground motion. The predominant mechanism that would cause damage to both CDSP and CSNF WPs is SCC, which would result in diffusive releases of radionuclides.

**ES9.2.4.2[a] Seismic Fault Displacement Modeling Case**

The Seismic FD Modeling Case includes disruption of WPs and DSs by the displacement of faults. Figure ES-56[a] shows the expected annual dose histories for the Seismic FD Modeling Case for the first 10,000 years after closure and for the postclosure period from 10,000 to one million years. The expected annual dose accounts for aleatory uncertainty about the number, type, and locations of disrupted DSs and WPs. The mean, median, and 5th and 95th percentile curves on Figure ES-56[a] show uncertainty in the distribution of expected annual dose, due to epistemic uncertainty regarding the behavior of the repository system during and after fault displacement events. These figures show the maximum mean annual dose for the first 10,000 years after closure; the calculated results indicate that the maximum mean annual value is $1.5 \times 10^{-3}$ millirem. The maximum median projected dose for the postclosure period from 10,000 to one million years is calculated to be $1.1 \times 10^{-2}$ millirem.

Figure ES-57[a] shows that $^{99}$Tc and $^{129}$I dominate the dose for the first 5,000 years after closure, and $^{99}$Tc and $^{239}$Pu dominate the dose between 5,000 and 10,000 years after closure.
Figure ES-57b[a] shows that $^{239}\text{Pu}$ dominates the mean annual dose up to 200,000 years postclosure, and $^{242}\text{Pu}$, $^{237}\text{Np}$, and $^{226}\text{Ra}$ dominate the mean annual dose for the remainder of the postclosure period from 200,000 to one million years.

**ES9.2.5[a] Total Mean Annual Dose to the Reasonably Maximally Exposed Individual for the Repository System**

Figure ES-58[a] shows the contribution to the total mean annual dose histories for the Drip Shield Early Failure (EF), Waste Package EF, Igneous Intrusion, Volcanic Eruption, Seismic GM, and Seismic FD Modeling Cases. Figure ES-58[a] shows that the Seismic GM and Igneous Intrusion Modeling Cases provide the largest contributions to the total mean annual dose for the postclosure period from 10,000 to one million years. The Seismic GM Modeling Case includes general corrosion processes for the postclosure period from 10,000 to one million years. Figure ES-58[a] shows that the events that most affect the total mean annual dose are seismic ground motion, igneous intrusions, and WP failure due to general corrosion.

**ES9.3[a] Comparison of Annual Dose with Postclosure Individual and Groundwater Protection Standards**

**ES9.3.1[a] Individual Protection Standard**

The results provided by the TSPA-LA Model include calculations of the total mean annual dose to the RMEI in any year during the next 10,000 years after repository closure (NRC Proposed Rule 10 CFR 63.303(a) [DIRS 178394]) and the total median annual dose to the RMEI in any year from 10,000 years after repository closure through the period of geologic stability (NRC Proposed Rule 10 CFR 63.303(b) [DIRS 178394]). According to NRC Proposed Rule 10 CFR 63.311 [DIRS 178394], the postclosure individual protection standard is 15 millirem up to 10,000 years postclosure, and 350 millirem after 10,000 years, but within the period of geologic stability (one million years). The TSPA-LA Model results, shown on Figures ES-40[a] and ES-41[a], which refer to distribution of total expected annual dose, show that the maximum projected total mean and total median annual doses to the RMEI are estimated to be about 0.24 millirem (Figure ES-40[a]) and 0.96 millirem (Figure ES-41[a]), respectively. These results demonstrate that the total mean annual dose to the RMEI in any year during the next 10,000 years after repository closure is less than the individual protection standard of 15 millirem per NRC Proposed Rule 10 CFR 63.311(a)(1) [DIRS 178394]. In addition, the highest projected dose values, mean or median, throughout the period of geologic stability are more than two orders of magnitude below the individual protection limit of 350 millirem per 10 CFR 63.311(a)(2) [DIRS 178394].

**Uncertainty/Sensitivity Results**

For different time frames in the analysis, different epistemic parameters emerge as important to the overall uncertainty in the results. Table ES-1[a] lists summary results of the sensitivity analysis. The important parameters listed on Table ES-1[a] are as follows:

- **IGRATE.** This parameter is the probability of an igneous event expressed as the annual frequency of an intersection of the repository by a volcanic dike. Uncertainty in this
parameter arises from epistemic uncertainty about igneous activity that may affect the repository.

- **SCCTHRP.** This parameter is the residual stress threshold for the Alloy 22 WP outer barrier, expressed as a percentage of the yield strength. If the residual stress in the WP outer barrier exceeded this threshold value, stress corrosion cracks could form, which could allow radionuclides to migrate from the WP. The primary causes of residual stresses in the WP outer barrier would be high peak-ground-velocity seismic ground motions, which may cause impacts from WP to WP, from WP to emplacement pallet, and from WP to DS. These impacts could cause dynamic loads that could dent the WP, resulting in structural deformation with residual stresses that could make the material susceptible to SCC.

- **SZGWSPDM.** This SZ flow and transport parameter is the logarithm of the scale factor for the groundwater specific discharge multiplier, which accounts for the epistemic uncertainty in the discharge flow rate used to compute advective radionuclide transport. This uncertainty parameter is applied to all of the climate states. Values for this parameter are sampled from an empirical cumulative distribution function; the technical basis for that distribution is documented in *Saturated Zone Flow and Transport Model Abstraction* (SNL 2008 [DIRS 183750], Section 6.5.2.1).

- **WDGCA22.** This parameter relates to the temperature dependence of the Alloy 22 WP outer barrier general corrosion rate. This uncertainty parameter determines the magnitude of this temperature dependence and directly influences the short-term and long-term general corrosion rates of the Alloy 22. Larger values of WDGCA22 result in earlier, higher general corrosion rates during the thermal period, and lower long-term corrosion rates when the repository temperatures are near the ambient *in situ* temperature.

The parameters in Table ES-1[a] that most affect the total uncertainty in the TSPA-LA Model are factors that govern degradation of the WPs, the occurrence of damage from seismic events, and the frequency with which igneous intrusions occur.

<table>
<thead>
<tr>
<th>Time After Closure (years)</th>
<th>Two Most Important Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>3,000</td>
<td>SCCTHRP IGRATE</td>
</tr>
<tr>
<td>5,000</td>
<td>SCCTHRP IGRATE</td>
</tr>
<tr>
<td>10,000</td>
<td>SCCTHRP IGRATE</td>
</tr>
<tr>
<td>125,000</td>
<td>IGRATE SZGWSPDM</td>
</tr>
<tr>
<td>250,000</td>
<td>IGRATE SZGWSPDM</td>
</tr>
<tr>
<td>500,000</td>
<td>IGRATE WDGCA22</td>
</tr>
<tr>
<td>1,000,000</td>
<td>IGRATE WDGCA22</td>
</tr>
</tbody>
</table>

Sources: Appendix K[a], Figure K8.1-2[a] and Figure K8.2-2[a]; output DTN: MO0801TSPAMVAC.000 [DIRS 185080].
ES9.3.2[a] Groundwater Protection Standard

The separate standards for protection of groundwater in NRC Proposed Rule 10 CFR 63.331 ([DIRS 180319], Table 1) stipulate that the releases of radionuclides in groundwater at the location of the RMEI should not cause the level of radioactivity in the representative water volume of 3,000 acre-feet of water (10 CFR 63.332(a)(3) [DIRS 180319]) to exceed the groundwater protection standards. The regulation does not require that evaluation of the groundwater protection standards include very unlikely events (NRC Proposed Rule 10 CFR 63.342(b) and (c)(1) [DIRS 178394]).

Figures ES-59[a], ES-60[a], and ES-61[a] show the projections for the performance measures of the separate standards for protection of groundwater in the representative volume of 3,000 acre-ft of water. Figure ES-59[a] shows the projections of the combined $^{226}$Ra and $^{228}$Ra activity concentrations, excluding natural background. Figure ES-60[a] shows the combined activity concentrations of all alpha emitters (including $^{226}$Ra but without radon and uranium isotopes), excluding natural background. Figure ES-61[a] shows the dose from beta-and photon-emitting radionuclides in the groundwater at the location of the RMEI, expressed in terms of annual dose to the whole body or any organ of a human receptor resulting from drinking two liters of this water per day. The TSPA-LA Model results show that the projected releases from the repository will meet the NRC separate standards for protection of groundwater in NRC Proposed Rule 10 CFR 63.331 ([DIRS 180319], Table 1).

ES9.4[a] Human Intrusion Scenario

The TSPA-LA Model was used to simulate a Human Intrusion Scenario in order to address the second requirement of the human intrusion standard (10 CFR 63.321(b) [DIRS 178394]). To calculate dose for all environmental pathways per 10 CFR 63.321(c) [DIRS 178394], the TSPA-LA Model used a probabilistic approach analogous to that used to evaluate conformance with the individual protection and groundwater protection standards.

The estimates of WP degradation suggest that, using current technology, a degraded WP could not be penetrated by drilling before about 200,000 years postclosure. Consequently, the analysis considered the effects of a drilling intrusion at 200,000 years. Figure ES-62[a] shows the expected annual dose that could result from a drilling intrusion 200,000 years after repository closure. The expected annual dose accounts for aleatory uncertainty about the type of WP intersected by the drill and location of the intersected WP. The mean, median, and 5th and 95th percentiles of the distribution of expected annual dose reflect epistemic uncertainty due to incomplete knowledge of the behavior of the physical system during and after the drilling intrusion.

The values on Figure ES-62[a] represent the dose from a single WP and are not combinations of releases from other WPs that may fail due to other processes. The mean and median annual doses from human intrusion are estimated to be less than 0.014 millirem. These results indicate that releases from a human intrusion would result in doses well below the human intrusion individual protection standard of 350 millirem annual individual dose to the RMEI during the postclosure period from 200,000 to one million years.
ES10[a] SUMMARY OF THE RESULTS OF THE TSPA-LA MODEL

The TSPA-LA Model was applied to the assessment of total system performance of the Yucca Mountain repository based on FEPs that could affect total system performance. The TSPA-LA analyses incorporate uncertainty in input data and submodel performance and use the validated TSPA-LA Model.

The TSPA-LA Model simulation/analysis periods cover 10,000 years after repository closure and from 10,000 years to the one-million-year period of geologic stability (NRC Proposed Rule 10 CFR 63.302 [DIRS 178394]). The 10,000-year simulations were extended an additional 10,000 years to assess whether or not the trends present at the end of 10,000 years continued beyond that time. The results of the analyses showed that the period between 10,000 years to 20,000 years after repository closure did not display any significant changes to the trends observed from 0 to 10,000 years, providing confidence in the conclusions regarding the 10,000-year period.

The TSPA-LA Model results demonstrate that the projected maximum mean dose to the RMEI in any year during the next 10,000 years after repository closure is less than the individual protection standard after permanent closure in NRC Proposed Rule 10 CFR 63.311(a)(1) [DIRS 178394], which describes the limits on radionuclides in the representative volume. The TSPA-LA Model analyses also indicate the performance of the repository system provides significant protection to groundwater. The results show that concentrations in the groundwater are likely to be well below the separate standards for the protection of groundwater in NRC Proposed Rule 10 CFR 63.331 ([DIRS 180319], Table 1). The results suggest the mean annual drinking water dose to any organ and to the whole body from beta- and photon-emitting radionuclides is likely to be well below the separate standards for the protection of groundwater.

The physiographic setting, topography, climate, area geology, and soil characteristics at the site of the Yucca Mountain repository are favorable for restricting the amount of infiltration of precipitation into the subsurface. The reduced infiltration along with rock characteristics, ambient and perturbed subsurface environmental conditions, and the geometry of emplacement drifts will further limit the amount of liquid water available to enter the drifts. Features of the waste form and other components of the EBS, together with limitations due to the solubility of radionuclides and the subsurface geology and hydrology, will limit the release, rate of release, and transport of radionuclides to the SZ beneath the repository. Only a small fraction of the radionuclide inventory is projected to be released from the EBS, move down through the UZ beneath the repository, and enter the SZ. Sorption and diffusion of radionuclides into the UZ will further reduce the concentrations of radionuclides entering the SZ. After the migrating radionuclides enter the SZ, the TSPA-LA Model results indicate that the characteristics of the rock, soil, and the hydrologic and geochemical environmental factors in the SZ will combine to retard radionuclide transport and reduce the rate of radionuclide transport to the accessible environment. Including igneous and seismic phenomena, the TSPA-LA Model analysis indicates that the repository will, with a high degree of confidence, perform in a manner that protects the natural environment and future human populations in the area.
Source: Modified from SNL 2007 [DIRS 182145], Figure 6.5.2.1-1[a].

NOTE: The model boundary is the same as the 1999 unsaturated zone flow model domain of the TSPA-SR.

Figure ES-12[a]. Topographic Map of the Yucca Mountain Site Showing Differences in Slope Characteristics North and South of Drill Hole Wash
Figure ES-40[a]. Total Expected Annual Dose for 10,000 Years after Repository Closure

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; MO0710PLOTSFIG.000 [DIRS 185207]; and MO0709TSPAREGS.000 [DIRS 182976].
Total System Performance Assessment Model/Analysis for the License Application

Figure ES-41[a]. Total Expected Annual Dose for 1,000,000 Years after Repository Closure

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; MO0710PLOTSFIG.000 [DIRS 185207]; and MO0709TSPAREGS.000 [DIRS 182976].
Figure ES-42[a]. Contribution of Individual Radionuclides to Total Mean Annual Dose for 10,000 Years after Repository Closure
Figure ES-43[a]. Contribution of Individual Radionuclides to Total Mean Annual Dose for 1,000,000 Years after Repository Closure

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; MO0710PLOTFIG.000 [DIRS 185207]; and MO0709TSPAREGS.000 [DIRS 182976].
Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0710PLOTSFIG.000 [DIRS 185207].

Figure ES-44[a]. Annual Dose for the Nominal Scenario Class Modeling Case for the Post-10,000-Year Period
Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0710PLOTSFIG.000 [DIRS 185207].

Figure ES-45[a]. Mean Annual Dose Contributions from Major Radionuclides for the Nominal Scenario Class Modeling Case for the Post-10,000-Year Period
Figure ES-46[a]. Expected Annual Dose for the Drip Shield Early Failure Modeling Case for (a) the First 10,000 Years after Repository Closure and (b) Post-10,000-Year Period

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0710PLOTSFIG.000 [DIRS 185207].
Mean Annual Dose Contributions from Major Radionuclides for the Drip Shield Early Failure Modeling Case for (a) the First 10,000 Years after Repository Closure and (b) Post-10,000-Year Period

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0710PLOTSFIG.000 [DIRS 185207].

Figure ES-47[a]. Mean Annual Dose Contributions from Major Radionuclides for the Drip Shield Early Failure Modeling Case for (a) the First 10,000 Years after Repository Closure and (b) Post-10,000-Year Period
Figure ES-48[a]. Expected Annual Dose for the Waste Package Early Failure Modeling Case for (a) the First 10,000 Years after Repository Closure and (b) Post-10,000-Year Period

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0710PLOTSFIG.000 [DIRS 185207].
Figure ES-49[a]. Mean Annual Dose Contributions from Major Radionuclides for the Waste Package Early Failure Modeling Case for (a) the First 10,000 Years after Repository Closure and (b) Post-10,000-Year Period

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0710PLOTSFIG.000 [DIRS 185207].
Figure ES-50[a]. Expected Annual Dose for the Igneous Intrusion Modeling Case for (a) 10,000 Years after Repository Closure and (b) Post-10,000-Year Period.
Figure ES-51[a]. Mean Annual Dose Contributions from Major Radionuclides for the Igneous Intrusion Modeling Case for (a) the First 10,000 Years after Repository Closure and (b) Post-10,000-Year Period.

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0710PLOTSFIG.000 [DIRS 185207].
Figure ES-54[a]. Expected Annual Dose for the Seismic Ground Motion Modeling Case for (a) 10,000 Years after Repository Closure and (b) Post-10,000-Year Period

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0710PLOTSFIG.000 [DIRS 185207].
Figure ES-55[a]. Mean Annual Dose Contributions from Major Radionuclides for the Seismic Ground Motion Modeling Case for (a) the First 10,000 Years after Repository Closure and (b) Post-10,000-Year Period.
Figure ES-56[a]. Expected Annual Dose for the Seismic Fault Displacement Modeling Case for (a) 10,000 Years after Repository Closure and (b) Post-10,000-Year Period

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0710PLOTSFIG.000 [DIRS 185207].
Figure ES-57[a]. Mean Annual Dose Contributions from Major Radionuclides for the Seismic Fault Displacement Modeling Case for (a) 10,000 Years after Repository Closure and (b) Post-10,000-Year Period
Total System Performance Assessment Model/Analysis for the License Application

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0709TSPAREGS.000 [DIRS 182976].

Figure ES-58[a]. Total Mean Annual Dose and Median Annual Doses for Each Modeling Case for (a) 10,000 Years after Repository Closure and (b) Post-10,000-Year Period

MDL-WIS-PA-000005 REV 00 AD 01  FES-18[a]  March 2008
Figure ES-59[a]. Combined $^{226}$Ra and $^{228}$Ra Activity Concentrations, Excluding Natural Background, for Likely Features, Events, and Processes Using Nominal, Early Failure, and Seismic Ground Motion Damage Processes

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0710PLOTSFIG.000 [DIRS 185207].
Figure ES-60[a]. Combined Activity Concentrations of All Alpha Emitters (including $^{226}$Ra but without radon and uranium isotopes), Excluding Natural Background, for Likely Features, Events, and Processes Using Nominal, Early Failure, and Seismic Ground Motion Damage Processes.
Figure ES-61[a]. Mean Annual Drinking Water Dose from Combined Beta and Photon Emitters for Likely Features, Events, and Processes using the Nominal, Early Failure, and Seismic Ground Motion Damage Processes

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0710PLOTSFIG.000 [DIRS 185207].
Figure ES-62[a]. Expected Annual Individual Dose at the RMEI Location from a Human Intrusion 200,000 Years after Repository Closure

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0710PLOTFIG.000 [DIRS 185207].
1[a]. PURPOSE

1.1[a] INTRODUCTION

This addendum updates the results of the Total System Performance Assessment for the License Application (TSPA-LA) Model presented in Total System Performance Assessment Model/Analysis for the License Application (the parent document). The updated results from TSPA-LA Model v5.005 incorporated changes to a supporting document, Saturated Zone Flow and Transport Model Abstraction (SNL 2008 [DIRS 183750]), amended after TSPA-LA Model v5.000 results in the parent document were completed. In addition, this addendum presents TSPA-LA results that address the issues identified and described in Appendix P. The issues were identified during detailed analysis, checking, and review activities. These issues were primarily related to minor inaccuracies in model implementation and identification of undocumented or unintended conservatisms or non-conservatisms. Appendix P[a] of this addendum includes updated tables (Tables P-6[a] and P-7[a]) that summarize the changes made in the TSPA-LA Model to address these issues. These additional analyses are presented in this addendum according to the review criteria outlined in Technical Work Plan for: Total System Performance Assessment FY 07-08 Activities (SNL 2008 [DIRS 184920], Sections 2.1.4 and 2.3.5.2.1).

For clarity, the general outline of the parent document is preserved in this addendum. In sections without any changes relative to the parent document, the text from the parent document is not repeated. Instead, the corresponding section in this addendum simply indicates that there are no changes, implicitly referring the reader to the same section of the parent document. Documentation provided in this addendum consists of a combination of supplemental and revised information. Section, figure, or table numbers cited in the text with [a] refer to this addendum, while those without it refer to the section, figure, or table number in the parent document. Section 1.10[a] lists the updates and additions to the parent document by section, which are included in this addendum.

The figures presented in this addendum, primarily reference output data tracking numbers (DTNs) containing data generated by the TSPA-LA Model. These output DTNs are described in Appendix B[a] and Appendix B of the parent document. Figure B-3[a] shows the relationship among the output DTNs referenced in this addendum and the output DTNs described in Appendix B of the parent document. Electronic copies of the figures generated for this addendum from TSPA-LA Model output are found in the output DTN: MO0710PLOTSFIG.000 [DIRS 185207] along with supporting documentation.

1.1.1[a] Governing Regulations

No change.

1.1.2[a] Total System Performance Assessment Methodology

No change.
1.1.3[a]  Treatment of Uncertainty

No change.

1.2[a]  TSPA-LA MODEL DEVELOPMENT PROCESS

No change.

1.3[a]  YUCCA MOUNTAIN SITE DESCRIPTION

No change.

1.4[a]  DESIGN OF YUCCA MOUNTAIN REPOSITORY SUBSURFACE FACILITIES

No change.

1.5[a]  GENERAL DESCRIPTION OF THE TSPA-LA MODEL

No change.

1.6[a]  CONCEPTUAL DESCRIPTION OF PROCESSES RELEVANT TO AN EVALUATION OF POSTCLOSURE PERFORMANCE IN THE ABSENCE OF DISRUPTIVE EVENTS

No change.

1.7[a]  CONCEPTUAL DESCRIPTION OF PROCESSES RELEVANT TO AN EVALUATION OF POSTCLOSURE PERFORMANCE AFTER THE OCCURRENCE OF DISRUPTIVE EVENTS

No change.

1.8[a]  CONSERVATISMS AND LIMITATIONS RELATED TO THE TSPA-LA MODEL

Section 1.8.2.5[a] addresses condition reports that have changed or are new since the parent document.

1.8.1[a]  Conservatisms Incorporated in the TSPA-LA Model

No change.

1.8.2[a]  Limitations of the TSPA-LA Model

Section 1.8.2.5[a] addresses condition reports that have changed or are new since the parent document.
1.8.2.1[a] Software Limitations

No change.

1.8.2.2[a] Computational Limitations

No change.

1.8.2.3[a] Data Limitations

No change.

1.8.2.4[a] Process Model Limitations

No change.

1.8.2.5[a] Condition Reports

The Total System Performance Assessment Model/Analysis for the License Application, Addendum 01, addresses the issues raised in the following condition reports (CRs) (cutoff date for inclusion: March 07, 2008):

- **Condition Report 11152** (Updates for draft Supplemental Environmental Impact Statement [SEIS]-TSPA)—CR 11152 identifies several issues in the TSPA-LA Model relating to the SEIS. The issues identified in the TSPA-LA Model log as described in the condition report have been addressed as documented in Appendix P[a].

- **Condition Report 11382** (Office of Chief Scientist)—CR 11382 identifies the following expectations of the Office of Chief Scientist: (1) provide an addendum to the Total System Performance Assessment Model/Analysis for the License Application to address issues identified in the development of the TSPA-LA Model, and (2) address the proposed changes to the regulations governing the preparation of the TSPA-LA Model in this addendum. The second item is documented in Section 1.1.1, Governing Regulations.

- **Condition Report 11655** (Addenda Planning Documentation)—CR-11655 concerns the issue that the current Technical Work Plan does not address the need for the scope of Addendum 01, and there is no documentation in the records package for the analyses or in the supplemental records package for the Technical Work Plan. However, this condition does not exist for this addendum. The planning for Addendum 01 is found in Technical Work Plan for: Total System Performance FY 07-08 Activities (SNL 2008 [DIRS 184920], Section 2.3.5.3). Although the word addendum does not appear, the content of Addendum 01 is planned to document additional analyses and associated changes, based on identified needs, in accordance with the review criteria described in Technical Work Plan for: Total System Performance FY 07-08 Activities (SNL 2008 [DIRS 184920], Sections 2.1.4 and 2.3.5.2.1). The additional analyses do not require any changes to the planning document and there is no impact to the TSPA-LA or this addendum.
• **Condition Report 11715** (Inconsistency in the Development of Water Table Temperature)—CR 11715 identifies the water table temperatures that are used in the evaluation of unsaturated zone (UZ) flow uncertainty and the impact on the weighting factors for UZ flow uncertainty cases used in the TSPA-LA Model. Despite the inconsistency in the development of the water table temperature boundary condition, the impact on the weighting factors used in the TSPA-LA Model is expected to be small.

• **Condition Report 11728** (Typographical Error in Table 4-1)—CR 11728 identifies that the DTN SN0701PAWPHIT1.001_R2 [DIRS 182961] addressed on lines 58 and 59 of Table 4-1 of the parent document was incorrectly identified as SN0701PAWPHIT.001_R2 [DIRS 182961]. This issue is corrected in Table 4-1[a].

• **Condition Report 11755** (EBS Radionuclide Transport Abstraction Typographical Error)—This condition report identifies that Table 8.2-4 in the EBS Radionuclide Transport Abstraction contains two parameter values for use in the water adsorption isotherm for corrosion products that are not the same as the output values in DTN: SN0703PAEBSTRA.001_R3 [DIRS 183217] or the values developed in the EBS Radionuclide Transport Abstraction (SNL 2007 [DIRS 177407], Section 6.3.4.3.2). The values on Table 8.2-4 are found in the output DTN file: SN0703PAEBSTRA.001-RTA Input Tables.Doc and were used in TSPA-LA Rev. 00 (Parameter Entry Form [PEF] 59). The correct values are found in the same DTN file: Corrosion Products Composite Isotherm 7-19-2007.xls as identified in the DTN readme file. This CR was discovered during the development of the TSPA-LA Rev 00 Addendum 01 and was corrected and verified during checking of the TSPA Input Database (PEF 203). The correct inputs were used to develop the TSPA-LA Addendum outputs.

• **Condition Report 11756** (Draft Data in DTN)—This condition report identifies output DTN: MO0708FREQCALC.000 [DIRS 183006] found in this addendum as containing files with content marked as DRAFT. Specifically, the DTN contains files named FreqDamageTAD.pdf and FreqRupture.pdf with headers on these documents indicating that they are DRAFT. The documentation issues raised in this CR do not involve the quality of the information; therefore, they are judged to have no impact on this addendum.

• **Condition Report 11759** (pdf of TSPA-LA)—The initial pdf file submitted to records for the TSPA-LA Rev00 inadvertently omitted two subsections, included some nonessential text regarding hidden headings, and appeared to have misnumbered pages in Appendix C. The first two items have been corrected and a new pdf has been submitted to records. It has been determined the third item (Appendix C page numbering) is not an issue as all pages were included and, therefore, does not impact the document. The documentation issues raised in this CR do not involve the quality of information and have no impact on this addendum. No further action is required.

• **Condition Report 11816** (Invert Thickness Change not in EBS RTA)—The range used for the TSPA parameter Diff Path Length Invert Top a is based on an earlier outdated invert configuration. The diffusive path length from the WP outer barrier to the mid-point of the invert is treated as an epistemic uncertain parameter.
(Diff_Path_Length_Invert_Top_a in Table 6.3.8-4 of the parent document) in the TSPA-LA Model. The updated average invert thickness would cause the diffusive path length used in the TSPA-LA Model to range from 0.47m to 1.41m. Because the diffusive path length parameter used in the TSPA-LA Model is based on a smaller value, the TSPA-LA Model conservatively overestimates diffusive releases from a breached WP to the invert relative to releases that would be obtained sampling an updated diffusive path length range. Therefore, not using the updated range is likely to have a negligible effect on the overall releases from the EBS calculated by the TSPA-LA Model. The issue raised in this CR has been determined to have no impact on this addendum.

1.9[a] DESCRIPTION OF THE TOTAL SYSTEM PERFORMANCE ASSESSMENT MODEL/ANALYSIS FOR THE LICENSE APPLICATION

No change.

1.10[a] DOCUMENT ORGANIZATION

The TSPA-LA parent document is organized in three volumes. This addendum follows the same organizational structure as the parent document. Only sections wherein additional information or results are presented are provided in this addendum. The information found in Volumes I[a], II[a], and III[a] of this addendum, along with the parent document, provides cross referencing that allows investigation of the structure and operation of the TSPA-LA Model files used to perform performance assessment calculations documented herein.

1.10.1[a] Volume I[a]

Volume I[a] of this addendum provides a description of the additional information required to document the TSPA-LA Model that was used for the analyses documented in this addendum. This includes information regarding direct inputs, parameters, and submodel descriptions as required to describe the TSPA-LA Model calculations and trace the sources of the TSPA-LA Model’s direct inputs. Volume I[a] also contains appropriate references to source information. Volume I of the parent document should be used in conjunction with the information provided in this addendum.

Section 1[a]: Purpose—Section 1[a] provides no additional information with respect to the features, events, and processes that led to the development of the scenario classes used in analyzing the performance of the repository system; the regulatory framework for the TSPA-LA Model; the overview of the natural and engineered barriers in the repository system, including site-description information, descriptions of the elements of the engineered barrier system (EBS), processes affecting water movement through the UZ and saturated zone (SZ), and descriptions of the model components; and a general description of the architecture of the TSPA-LA Model. All of these topics are discussed in the parent document and apply to the analyses presented in this addendum.

Section 2[a]: Quality Assurance—Section 2 of the parent document describes the applicable quality assurance procedures of *Quality Assurance Requirements and Description* (DOE 2007
[DIRS 182051]), along with descriptions and references to the methods used for the electronic management of information. There is no additional information provided in this addendum.

**Section 3[a]: Use of Software**—Section 3 of the parent document lists and describes the software used in the development of the TSPA-LA Model. For the analyses presented in this addendum, only additional software or changes in the software used for the model results presented in the parent document are listed in Section 3[a].

**Section 4[a]: Inputs**—Section 4[a] identifies the additional direct inputs used in the TSPA-LA Model results presented in this addendum, either by direct tabulations included in this document or through linkage to the appropriate sections of the GoldSim model file or TSPA-LA Model database. Section 4 of the parent document should be used in conjunction with the data provided in Section 4[a] of this addendum.

**Section 5[a]: Assumptions**—Section 5 of the parent document lists the assumptions directly used to perform the TSPA-LA Model analyses along with their basis. Section 5[a] includes no additional assumptions for the TSPA-LA Model results documented in this addendum.

**Section 6[a]: Model Description**—Section 6 of the parent document describes the TSPA-LA Model representation of the repository system, presents the scenario classes being analyzed, describes the modeling cases used to analyze the scenario classes, and provides references to the applicable sections of the TSPA-LA Model, the GoldSim model file, and supporting analyses. Section 6 of the parent document also includes detailed descriptions of the conceptual models, mathematical formulations, implementations of the submodels in the TSPA-LA Model, conservatisms, and alternate conceptual models. Section 6[a] provides additional information consisting of typographical corrections, omissions, or descriptions of changes or additions to the conceptual models, mathematical formulations, implementations of the submodels for the TSPA-LA Model, conservatisms, and alternate conceptual models necessary to document the additional analyses presented in this addendum. Section 6 of the parent document should be used in conjunction with the data provided in Section 6[a] of this addendum.

**1.10.2[a] Volume II[a]**

Volume II[a] contains the supplemental information supporting the TSPA-LA Model validation.

**Section 7[a]: Validation**—Section 7 of the parent document describes the validation of the TSPA-LA Model as required by Section 6.3 of SCI-PRO-006, *Models*. The model validation of the TSPA-LA Model is consistent with the intended use of the TSPA-LA Model and the required level of confidence. In addition, the TSPA-LA Model validation results presented in this addendum are consistent with the intended use of the TSPA-LA Model. Additional model validation results documented in Volume II of this addendum are presented to confirm that the TSPA-LA Model validation has been maintained for v5.005 as well as to enhance the overall level of confidence in the TSPA-LA Model.
• Computer code and input re-verification (Section 7.2[a]) including:
  – Verification testing for the Human Intrusion Submodel inadvertently omitted from the parent document (Section 7.2.4.1.12[a])
  – Summary of an assessment of the range of validity for all TSPA-LA Model submodels inadvertently omitted from the parent document (Section 7.2.6[a])

• Demonstration of Model Stability (Section 7.3[a])
  – Comparison between TSPA-LA Model v5.000 and v5.005 expected dose results (Section 7.3.1[a])
  – Reevaluation of the statistical stability of TSPA-LA Model v5.005 results (Section 7.3.1[a])
  – Confirmation of numerical accuracy of expected dose results for the Seismic Fault Displacement (FD) Modeling Case (Section 7.3.2.7[a])
  – Reevaluation of the temporal stability testing for the Human Intrusion Modeling Case as the result of a change to the time step size for this modeling case (Section 7.3.3.6[a])
  – Evaluation of the temporal stability of the Nominal Modeling Case (Section 7.3.3.7[a])

• Surrogate Waste Form Validation (Section 7.5[a])
  – Reevaluation of the adequacy of using commercial spent nuclear fuel (CSNF) as a surrogate for naval spent nuclear fuel (NSNF) using TSPA-LA Model v5.005 (Section 7.5.3[a])

• Reevaluation of the corroboration of the TSPA-LA Model results documented in the parent document with auxiliary analyses (Section 7.7[a]), including:
  – Updated analyses of single realizations for the Early Failure Scenario Class, the Igneous Intrusion Modeling Case, and the Seismic Ground Motion (GM) Modeling Case for 1,000,000 years, including additional analyses of outlier realizations (Section 7.7.1[a])
  – Additional analyses of single realizations including: (1) the Nominal Scenario Class (Section 7.7.1.5[a]), (2) a Seismic GM Modeling Case for 10,000 years (Section 7.7.1.7[a]), and (3) the Human Intrusion Scenario (Section 7.7.1.6[a])
  – Updated evaluation with a Simplified TSPA Analysis (Section 7.7.2[a])
  – Updated evaluation with the Electric Power Research Institute (EPRI) Analysis (Section 7.7.3[a])
Reevaluation of a comparison of results from the Performance Margin Analysis (Section 7.7.4[a]).

1.10.3[a] Volume III[a]

This volume contains the updated results for the TSPA-LA Model. These are detailed below.

Section 8[a]: Analyses—Section 8 of the parent document includes conclusions of the analyses as required by SCI-PRO-006. Section 8[a] of this addendum contains the updated results for the TSPA-LA Model performance analyses evaluating the postclosure performance of the repository and its compliance with U.S. Nuclear Regulatory Commission (NRC) Proposed Rule 10 CFR 63.113 [DIRS 180319] and the performance measures defined in proposed 10 CFR 63.303 [DIRS 178394] for the individual protection standard after permanent closure in proposed 10 CFR 63.311(a)(1) and (2) [DIRS 178394], the individual protection standard for human intrusion in 10 CFR 63.321(a)(1) and (2) [DIRS 178394], and the separate standards for protection of groundwater in 10 CFR 63.331, Table 1 [DIRS 180319]. The probabilistic analyses account for uncertainty and address features, events, and processes that could affect total system performance. Volume III[a] presents the updated results of analyses and calculations in the following areas:

- Comparison of TSPA-LA Model analyses with the performance measures defined in proposed 10 CFR 63.303 [DIRS 178394] for the individual protection standard after permanent closure in proposed 10 CFR 63.311(a)(1) and (2) [DIRS 178394], the individual protection standard for human intrusion in 10 CFR 63.321(a)(1) and (2) [DIRS 178394], and the separate standards for protection of groundwater in 10 CFR 63.331, Table 1 [DIRS 180319]

- System and subsystem performance analyses for the Nominal Scenario Class, including the Nominal Modeling Case; the Early Failure Scenario Class, including the Drip Shield Early Failure (EF) and Waste Package EF Modeling Cases; the Igneous Scenario Class, including both Igneous Intrusion and Volcanic Eruption Modeling Cases; and the Seismic Scenario Class, including the Seismic GM and FD Modeling Cases

- Analyses of the capabilities and importance of the upper and lower natural barriers and the EBS that have been identified as contributing to repository performance.

The results presented in this addendum represent an iterative process that reflects a rigorous model verification and implementation cycle.

Section 9[a]: Inputs and References—Section 9[a] provides additional sources of inputs, software, DTNs, and cited references.

Appendices

A. Acronyms and Abbreviations—No changes from the parent document.
B[a]. Data Tracking Numbers for the TSPA-LA Model—Appendix B[a] describes the contents of the output DTNs for the analyses presented in this addendum.

C[a]. Performance Margin Analysis—Appendix C[a] includes an update to Table C9-1 presented in the parent document; issue and impact assessments were not previously documented for the Performance Margin Analysis.

D[a]. Parameter Listing—Appendix D[a] refers to the TSPA Input Database, which contains a listing of all the additional parameters used to conduct the analyses presented in this addendum and the source(s) for each parameter. It also directs the reader to the appropriate sections in this document (Section 4[a] and Appendix K[a]) for further information on the addendum parameters.

E. Response to Review Comments from the International Review Team—No changes from the parent document.

F. Dynamically Linked Libraries Description and Feeds—No changes from the parent document.

G. Wiring Diagrams for Model Information Feeds—No changes from the parent document.

H[a]. Yucca Mountain Review Plan Acceptance Criteria—Appendix H[a] includes minor changes from the parent document to reference the proposed rule.

I[a]. Features, Events, and Processes Mapped to TSPA-LA Model—Appendix I[a] updates selected descriptions in Table I-2 from the parent document.

J[a]. Conceptual Structure of TSPA-LA—This addendum presents additional supplemental material in Appendix J[a], Section J3[a], which provides an overview of the underlying concepts used in the TSPA-LA Model that are described in Appendix J of the parent document.

K[a]. Uncertainty and Sensitivity Analysis Results—Appendix K[a] presents the distributions of results for each modeling case (uncertainty analyses) and identifies the uncertain parameters that predominantly contribute to the uncertainty in each modeling cases’ results (sensitivity analyses) for the analyses presented in this addendum.

L. Simplified TSPA—No changes from the parent document.

M[a]. Comparison with Electric Power Research Institute Analysis—Minor changes from the parent document are incorporated to rectify a mistaken reference to supporting documentation.

N. Derivation of Implementing Equations for Waste Package Parsing and Average Damage Area—No changes from the parent document.
O. Localized Corrosion Initiation Uncertainty Analysis—No changes from the parent document.

P[a]. Impact Assessments—Appendix P[a] includes updates to Tables P-6 and P-7 in the parent document indicating the issues that have been addressed in the updated results. In addition, Appendix P[a] includes a modification to the issue description and analysis of the expected impact documented in Section P13 of the parent document.
2[a]. QUALITY ASSURANCE

2.1[a] CONFIGURATION MANAGEMENT

No change.
3[a]. USE OF SOFTWARE

3.1[a] INTRODUCTION

Section 3 of the parent document describes the software used in the development of the TSPA-LA Model. For the analyses presented in this addendum, only additional software or changes in the software used for the model results presented in the parent document are listed in Section 3[a]. In addition, Table 3-1 has been revised with the additional software and is included as Table 3-1[a] of this addendum. In addition, Figure 3-2 of the parent document incorrectly identified the surface infiltration external process model. Therefore, the figure has been updated and is included as Figure 3-2[a] of this addendum.

3.2[a] ASHPLUME_DLL.LA

No change.

3.3[a] CWD

No change.

3.4[a] EXDOC_LA

No change.

3.5[a] FAR

No change.

3.6[a] FEHM

No change.

3.7[a] GETTHK_LA

No change.

3.8[a] GOLDSIM

A software problem report (SPR013420071203 [DIRS 184391]) was submitted for GoldSim version 9.60.100 (STN: 10344-9.60-01 [DIRS 181903]) as a result of errors in radionuclide ingrowth calculations for the source term elements (Appendix P[a], Table P-7[a], Item P20). A new service pack, GoldSim version 9.60.300 (STN: 10344-9.60-03 [DIRS 184387]) was issued to address the problem. The GoldSim service pack problem report is included in the software problem report (SPR013420071203 [DIRS 184391]). An impact assessment was conducted by comparing results obtained using GoldSim version 9.60.300 with results from GoldSim version 9.60.100. The software errors resulted in an insignificant impact to the TSPA-LA results documented in the parent document (Appendix P, Section P20). Analyses presented in this addendum use the updated software (GoldSim version 9.60.300).
3.8.1[a] Description of Software

No change.

3.8.2[a] Relationship to the TSPA-LA Model

GoldSim version 9.60.100 [DIRS 181903] was used for the TSPA-LA Model development and validation and analysis cases (v5.000) as documented in Section 3.8 of the parent document. GoldSim version 9.60.300 [DIRS 184387] was used for the TSPA-LA Model development and validation and analysis cases (v5.005) documented in this addendum.

A controlled version of GoldSim version 9.60.300 was used prior to a qualified version as allowed by SCI-PRO-006. After qualification, GoldSim version 9.60.300 was obtained from Software Configuration Management in accordance with the governing procedure, IM-PRO-003, Software Management, and installed. The GoldSim version 9.60.300 installation package documents the confirmation that the controlled version of GoldSim version 9.60.300 is identical to the qualified version of GoldSim version 9.60.300 obtained from Software Configuration Management.

3.8.3[a] Software Documentation

Table 3-8[a] is modified to list the additional software documents pertaining to GoldSim version 9.60.300 [DIRS 184387].

3.8.4[a] Range of Validation

The range of validation for the versions of GoldSim listed in Section 3.8.2[a] is defined by the documented functionality (i.e., requirements) and range(s) of acceptable inputs. The requirements are located in the respective requirements documents listed in Table 3-8[a]. The range(s) of acceptable inputs is discussed in the respective design and user documents listed in Table 3-8[a].

3.9[a] INTERPZDLL_LA

No change.

3.10[a] MFCP_LA

No change.

3.11[a] MKTABLE AND MKTABLE_LA

No change.

3.12[a] MVIEW

No change.
3.13[a]  PASSTABLE1D_LA
No change.

3.14[a]  PASSTABLE3D_LA
No change.

3.15[a]  PREWAP_LA
No change.

3.16[a]  SCCD
No change.

3.17[a]  SEEPAGEDLL_LA
No change.

3.18[a]  SOILEXP_LA
No change.

3.19[a]  SZ_CONVOLUTE
No change.

3.20[a]  TSPA_INPUT_DB
No change.

3.21[a]  WAPDEG
No change.

3.22[a]  CORROBORATIVE SOFTWARE USED
No change.
<table>
<thead>
<tr>
<th>Code</th>
<th>Version</th>
<th>Software Tracking Number</th>
<th>Operating System</th>
<th>DIRS Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASHPLUME_DLL_LA&lt;sup&gt;a1&lt;/sup&gt;</td>
<td>2.0</td>
<td>STN: 11117-2.0-00</td>
<td>Windows 2000</td>
<td>DIRS 181034</td>
</tr>
<tr>
<td>ASHPLUME_DLL_LA&lt;sup&gt;a2 a3&lt;/sup&gt;</td>
<td>2.1</td>
<td>STN: 11117-2.1-00</td>
<td>Windows 2000</td>
<td>DIRS 181035</td>
</tr>
<tr>
<td>ASHPLUME_DLL_LA&lt;sup&gt;a2 a3&lt;/sup&gt;</td>
<td>2.1</td>
<td>STN: 11117-2.1-01</td>
<td>Windows 2003</td>
<td>DIRS 180147</td>
</tr>
<tr>
<td>CWD&lt;sup&gt;a2&lt;/sup&gt;</td>
<td>2.0</td>
<td>STN: 10363-2.0-00</td>
<td>Windows 2000</td>
<td>DIRS 162809</td>
</tr>
<tr>
<td>CWD&lt;sup&gt;a2&lt;/sup&gt;</td>
<td>2.0</td>
<td>STN: 10363-2.0-01</td>
<td>Windows 2003</td>
<td>DIRS 181037</td>
</tr>
<tr>
<td>EXDOC_LA&lt;sup&gt;b1&lt;/sup&gt;</td>
<td>2.0</td>
<td>STN: 11193-2.0-00</td>
<td>Windows 2000</td>
<td>DIRS 182102</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Windows 2003</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Windows XP</td>
<td></td>
</tr>
<tr>
<td>FAR&lt;sup&gt;a1&lt;/sup&gt;</td>
<td>1.1</td>
<td>STN: 11190-1.1-00</td>
<td>Windows 2000</td>
<td>DIRS 180002</td>
</tr>
<tr>
<td>FAR&lt;sup&gt;a2&lt;/sup&gt;</td>
<td>1.2</td>
<td>STN: 11190-1.2-00</td>
<td>Windows 2000</td>
<td>DIRS 182225</td>
</tr>
<tr>
<td>FEHM&lt;sup&gt;a1&lt;/sup&gt;</td>
<td>2.23</td>
<td>STN: 10086-2.23-00</td>
<td>Windows 2000</td>
<td>DIRS 173139</td>
</tr>
<tr>
<td>FEHM&lt;sup&gt;a2&lt;/sup&gt;</td>
<td>2.24-01</td>
<td>STN: 10086-2.24-01-00</td>
<td>Windows 2000</td>
<td>DIRS 179419</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Windows 2003</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Windows XP</td>
<td></td>
</tr>
<tr>
<td>GetThk_LA&lt;sup&gt;a2 a3&lt;/sup&gt;</td>
<td>1.0</td>
<td>STN: 11229-1.0-00</td>
<td>Windows 2000</td>
<td>DIRS 181040</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Windows 2003</td>
<td></td>
</tr>
<tr>
<td>GoldSim&lt;sup&gt;a1&lt;/sup&gt;</td>
<td>9.60</td>
<td>STN: 10344-9.60-00</td>
<td>Windows 2000</td>
<td>DIRS 180224</td>
</tr>
<tr>
<td>GoldSim&lt;sup&gt;a2&lt;/sup&gt;</td>
<td>9.60.100</td>
<td>STN: 10344-9.60-01</td>
<td>Windows 2000</td>
<td>DIRS 181903</td>
</tr>
<tr>
<td>GoldSim&lt;sup&gt;a3&lt;/sup&gt;</td>
<td>9.60.300</td>
<td>STN: 10344-9.60-03</td>
<td>Windows 2000</td>
<td>DIRS 184387</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Windows 2003</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Windows XP</td>
<td></td>
</tr>
<tr>
<td>InterpZdll_LA&lt;sup&gt;a2 a3&lt;/sup&gt;</td>
<td>1.0</td>
<td>STN: 11107-1.0-00</td>
<td>Windows 2000</td>
<td>DIRS 167885</td>
</tr>
<tr>
<td>InterpZdll_LA&lt;sup&gt;a2 a3&lt;/sup&gt;</td>
<td>1.0</td>
<td>STN: 11107-1.0-01</td>
<td>Windows 2003</td>
<td>DIRS 181043</td>
</tr>
<tr>
<td>MFCP_LA&lt;sup&gt;a2 a3&lt;/sup&gt;</td>
<td>1.0</td>
<td>STN: 11071-1.0-00</td>
<td>Windows 2000</td>
<td>DIRS 167884</td>
</tr>
<tr>
<td>MFCP_LA&lt;sup&gt;a2 a3&lt;/sup&gt;</td>
<td>1.0</td>
<td>STN: 11071-1.0-01</td>
<td>Windows 2003</td>
<td>DIRS 181045</td>
</tr>
<tr>
<td>MkTable&lt;sup&gt;a1&lt;/sup&gt;</td>
<td>1.00</td>
<td>STN: 10505-1.00-00</td>
<td>Windows 2000</td>
<td>DIRS 174528</td>
</tr>
<tr>
<td>MkTable&lt;sup&gt;a2 a3&lt;/sup&gt;</td>
<td>1.0</td>
<td>STN: 11217-1.0-00</td>
<td>Windows 2000</td>
<td>DIRS 181047</td>
</tr>
<tr>
<td>MkTable&lt;sup&gt;a2 a3&lt;/sup&gt;</td>
<td>1.0</td>
<td>STN: 11217-1.0-01</td>
<td>Windows 2003</td>
<td>DIRS 181048</td>
</tr>
<tr>
<td>MView&lt;sup&gt;b1&lt;/sup&gt;</td>
<td>4.0</td>
<td>STN: 10072-4.0-01</td>
<td>Windows XP</td>
<td>DIRS 181049</td>
</tr>
<tr>
<td>PassTable1D_LA&lt;sup&gt;a1&lt;/sup&gt;</td>
<td>1.0</td>
<td>STN: 11142-1.0-00</td>
<td>Windows 2000</td>
<td>DIRS 169130</td>
</tr>
<tr>
<td>PassTable1D_LA&lt;sup&gt;a1&lt;/sup&gt;</td>
<td>1.0</td>
<td>STN: 11142-1.0-01</td>
<td>Windows 2003</td>
<td>DIRS 181050</td>
</tr>
<tr>
<td>PassTable1D_LA&lt;sup&gt;a2 a3&lt;/sup&gt;</td>
<td>2.0</td>
<td>STN: 11142-2.0-00</td>
<td>Windows 2000</td>
<td>DIRS 181051</td>
</tr>
<tr>
<td>PassTable3D_LA&lt;sup&gt;a1&lt;/sup&gt;</td>
<td>1.0</td>
<td>STN: 11143-1.0-00</td>
<td>Windows 2000</td>
<td>DIRS 168980</td>
</tr>
</tbody>
</table>
### Table 3-1[a]. TSPA-LA Model Software Codes (Continued)

<table>
<thead>
<tr>
<th>Code</th>
<th>Version</th>
<th>Tracking Number</th>
<th>Operating System</th>
<th>DIRS Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>PassTable3D_LA</td>
<td>1.0</td>
<td>STN: 11143-1.0-01</td>
<td>Windows 2003</td>
<td>DIRS 181052</td>
</tr>
<tr>
<td>PassTable3D_LA</td>
<td>2.0</td>
<td>STN: 11143-2.0-00</td>
<td>Windows 2000, Windows 2003</td>
<td>DIRS 182556</td>
</tr>
<tr>
<td>PREWAP_LA</td>
<td>1.1</td>
<td>STN: 10939-1.1-00</td>
<td>Windows 2000</td>
<td>DIRS 181053</td>
</tr>
<tr>
<td>SCCD</td>
<td>2.01</td>
<td>STN: 10343-2.01-00</td>
<td>Windows 2000</td>
<td>DIRS 181157</td>
</tr>
<tr>
<td>SEEPAGEDLL_LA</td>
<td>1.2</td>
<td>STN: 11076-1.2-00</td>
<td>Windows 2000</td>
<td>DIRS 173435</td>
</tr>
<tr>
<td>SEEPAGEDLL_LA</td>
<td>1.3</td>
<td>STN: 11076-1.3-00</td>
<td>Windows 2000, Windows 2003</td>
<td>DIRS 180318</td>
</tr>
<tr>
<td>SEEPAGEDLL_LA</td>
<td>1.3</td>
<td>STN: 11076-1.3-01</td>
<td>Windows 2003</td>
<td>DIRS 181058</td>
</tr>
<tr>
<td>SoilExp_LA</td>
<td>1.0</td>
<td>STN: 10933-1.0-00</td>
<td>Windows 2000</td>
<td>DIRS 167883</td>
</tr>
<tr>
<td>SZ_Convolute</td>
<td>3.0</td>
<td>STN: 10207-3.0-00</td>
<td>Windows 2000</td>
<td>DIRS 164180</td>
</tr>
<tr>
<td>SZ_Convolute</td>
<td>3.10.01</td>
<td>STN: 10207-3.10.01-00</td>
<td>Windows 2000, Windows 2003</td>
<td>DIRS 181060</td>
</tr>
<tr>
<td>TSPA_Input_DB</td>
<td>2.2</td>
<td>STN: 10931-2.2-00</td>
<td>Windows 2000</td>
<td>DIRS 181061</td>
</tr>
<tr>
<td>TSPA_Input_DB</td>
<td>2.2</td>
<td>STN: 10931-2.2-01</td>
<td>Windows 2003</td>
<td>DIRS 181062</td>
</tr>
<tr>
<td>WAPDEG</td>
<td>4.07</td>
<td>STN: 10000-4.07-00</td>
<td>Windows 2000</td>
<td>DIRS 181774</td>
</tr>
<tr>
<td>WAPDEG</td>
<td>4.07</td>
<td>STN: 10000-4.07-01</td>
<td>Windows 2003</td>
<td>DIRS 181064</td>
</tr>
</tbody>
</table>

- **a1** Codes are used only for the TSPA-LA Model development (See note below).
- **a2** Codes used in the TSPA-LA Model that are used for the TSPA-LA Model development (See note below) and to develop results and conclusions in Section 8 of the parent document.
- **a3** Codes used in the TSPA-LA Model that are used for the TSPA-LA Model development (See note below) and to develop results and conclusions in Section 8[a] of this addendum.
- **b1** Code is a pre- or post-processor that does not require GoldSim to run codes that are used for the TSPA-LA Model development (See NOTE below) and to develop results and conclusions in Section 8.

**NOTE:** TSPA-LA Model development should not be confused with model development as described in SCI-PRO-006. TSPA-LA Model development is merely a phrase to represent the draft model versions (i.e., v4.001 to v4.047) that were created before finalizing the model (e.g., v5.000) presented in the parent document and v5.001 to v5.004 that were created before finalizing the model v5.005 presented in this addendum. The draft model versions, v4.001 to v4.047, were submitted as part of the records package for the parent document. The draft model versions, v5.001 to v5.004, are to be submitted as part of the records package for this addendum. All software codes used for the results presented in this document are on the software baseline.
Table 3-8[a]. GoldSim Software Documents for Version 9.60.300 (STN: 10344-9.60-30)

<table>
<thead>
<tr>
<th>Description</th>
<th>Document ID</th>
<th>DIRS Number</th>
<th>Tracking Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Requirements Document (RD)</td>
<td>10344-RD-9.60-00</td>
<td>181106</td>
<td>MOL.20070416.0330</td>
</tr>
<tr>
<td>Design Document (DD)</td>
<td>10344-DD-9.60-01</td>
<td>181107</td>
<td>MOL.20070416.0338</td>
</tr>
<tr>
<td>User Information Document (UID)</td>
<td>10344-UID-9.60-00</td>
<td>181108</td>
<td>MOL.20070416.0339</td>
</tr>
<tr>
<td>Software Validation Report (SVR)</td>
<td>10344-SVR-9.60-03-WIN2000</td>
<td>185016</td>
<td>MOL.20080125.0059</td>
</tr>
<tr>
<td>Software Validation Report (SVR)</td>
<td>10344-SVR-9.60-03-WIN2003</td>
<td>185017</td>
<td>MOL.20080125.0061</td>
</tr>
<tr>
<td>Software Validation Report (SVR)</td>
<td>10344-SVR-9.60-03-WINXP</td>
<td>185018</td>
<td>MOL.20080125.0057</td>
</tr>
</tbody>
</table>
TSPA-LA Software Architecture

Output Parameters

- $f_s$: Fraction of WPs with Sweps
- EBS: Engineered Barrier System
- $Q_s$: Seepage Rate
- $P_{CO_2}$: Partial Pressure of CO$_2$
- $\Sigma CO_2^+$: Carbonate Concentration
- $pH$: pH
- $q_p$: Liquid Flux
- $q_l$: Infiltration Flux
- $H$: Hydrologic Properties
- $SP$: Seepage Parameters
- $RS$: Rock Strength
- $RF$: Rock Size and Number

Legend

- Preprocessor
- TSPA Model DLL
- Connection in GoldSim

Figure 3-2[a]. TSPA-LA Software Architecture
4[a]. INPUTS

4.1[a] DIRECT INPUTS

Direct inputs are those parameters whose values are used by the TSPA-LA Model to compute the results presented in this document. This information is stored in the TSPA Input Database and is described in Section 4.7 of the parent document. Table 4-1 lists the direct input required for the analyses in the parent document. Table 4-1[a] of this addendum lists the additional direct input required for the analyses documented in this addendum and associates it with a reference source and a PEF number (see Section 4.3 of the parent document for an overview of PEFs).

The direct inputs listed in Table 4-1[a], except where noted, reflect parameter values that were corrected in TSPA-LA Model v5.005, rather than new direct inputs to the TSPA-LA Model, and are therefore cited in Section 6 of the parent document. The discussions presented in Section 6 of the parent document for these parameters remain unchanged. Line items starting with #129 represent new direct input and are cited in Section 6[a] of this addendum. All other references in Table 4-1 of the parent document remain unchanged.

4.2[a] TSPA-LA MODEL-GENERATED PARAMETERS

The TSPA-LA Model requires the generation of many parameters (often incorporated into large data files) that are created by preprocessing methods (i.e., created prior to running the TSPA-LA Model). These parameters are captured in output DTNs along with explanations for how they were generated. The use of output DTNs in the TSPA-LA Model is described at various locations in the parent document. PEFs that reference new output DTNs generated to support the analyses documented in this addendum are listed in Table 4-2[a].

4.3[a] PARAMETER ENTRY FORMS

No change.

4.4[a] TRACEABILITY OF INPUTS

No change.

4.5[a] CRITERIA

No change.

4.6[a] CODES AND STANDARDS

No change.

4.7[a] TSPA INPUT DATABASE

No change.
INTENTIONALLY LEFT BLANK
<table>
<thead>
<tr>
<th>Line #</th>
<th>Document _ID</th>
<th>Reference _Document</th>
<th>Document DIRS</th>
<th>DTN</th>
<th>DTN DIRS</th>
<th>PEF</th>
</tr>
</thead>
<tbody>
<tr>
<td>14 a</td>
<td>ANL-EBS-MD-000033 Rev 06</td>
<td>Engineered Barrier System: Physical and Chemical Environment</td>
<td>NA</td>
<td>SN0701PAEBSPCE.001_R1</td>
<td>180523</td>
<td>214</td>
</tr>
<tr>
<td>58 a</td>
<td>ANL-MGR-GS-000003</td>
<td>Number of Waste Packages Hit by Igneous Events</td>
<td>NA</td>
<td>SN0701PAWPHIT1.001_R2</td>
<td>182961</td>
<td>30, 61</td>
</tr>
<tr>
<td>66 a</td>
<td>ANL-WIS-MD-000010 Rev 06</td>
<td>Dissolved Concentration Limits of Elements with Radioactive Isotopes</td>
<td>NA</td>
<td>MO0702PAFLUORI.000_R1</td>
<td>181219</td>
<td>215</td>
</tr>
<tr>
<td>70 a</td>
<td>ANL-WIS-MD-000020 Rev 01 AD01</td>
<td>Initial Radionuclide Inventories</td>
<td>NA</td>
<td>SN0310T0505503.004_R0</td>
<td>168761</td>
<td>202</td>
</tr>
<tr>
<td>73 a</td>
<td>ANL-WIS-PA-000001 Rev 03</td>
<td>EBS Radionuclide Transport Abstraction</td>
<td>NA</td>
<td>SN0703PAEBSRTA.001_R3</td>
<td>183217</td>
<td>203</td>
</tr>
<tr>
<td>79 a</td>
<td>MDL-EBS-PA-000004 Rev 03</td>
<td>Waste Form and In-Drift Colloids-Associated Radionuclide Concentrations: Abstraction and Summary</td>
<td>NA</td>
<td>MO0701PACSNFCP.000_R1</td>
<td>180439</td>
<td>213</td>
</tr>
<tr>
<td>82 a</td>
<td>MDL-EBS-PA-000004 Rev 03</td>
<td>Waste Form and In-Drift Colloids-Associated Radionuclide Concentrations: Abstraction and Summary</td>
<td>NA</td>
<td>MO0701PAIRONCO.000_R1</td>
<td>180440</td>
<td>219</td>
</tr>
<tr>
<td>101 a</td>
<td>MDL-NBS-HS-000008 Rev 02 AD01</td>
<td>Radionuclide Transport Models Under Ambient Conditions</td>
<td>NA</td>
<td>LA0408AM831341.001_R0</td>
<td>171584</td>
<td>217, 218</td>
</tr>
<tr>
<td>103 a</td>
<td>MDL-NBS-HS-000008 Rev 02 AD01</td>
<td>Radionuclide Transport Models Under Ambient Conditions</td>
<td>NA</td>
<td>LB0701PAKDESEN.001_R0</td>
<td>179299</td>
<td>216, 218</td>
</tr>
<tr>
<td>105 a</td>
<td>MDL-NBS-HS-000019 Rev 01 AD01</td>
<td>Abstraction of Drift Seepage</td>
<td>NA</td>
<td>LB0702PASEEP02.001_R1</td>
<td>181635</td>
<td>201</td>
</tr>
<tr>
<td>108 a</td>
<td>MDL-NBS-HS-000020 Rev 02 AD02</td>
<td>Particle Tracking Model and Abstraction of Transport Processes</td>
<td>NA</td>
<td>LA0701PANS02BR.003_R2</td>
<td>180497</td>
<td>218</td>
</tr>
<tr>
<td>110 a</td>
<td>MDL-NBS-HS-000020 Rev 02 AD02</td>
<td>Particle Tracking Model and Abstraction of Transport Processes</td>
<td>NA</td>
<td>LA0702PANS02BR.001_R1</td>
<td>180322</td>
<td>207</td>
</tr>
<tr>
<td>113 a</td>
<td>MDL-NBS-HS-000008 Rev 02 AD01</td>
<td>Radionuclide Transport Models Under Ambient Conditions</td>
<td>NA</td>
<td>LB0702PAUZMTDF.001_R1</td>
<td>180776</td>
<td>218</td>
</tr>
<tr>
<td>115 a</td>
<td>MDL-NBS-HS-000020 Rev 02 AD02</td>
<td>Particle Tracking Model and Abstraction of Transport Processes</td>
<td>NA</td>
<td>MO0704PAFEHMBR.001_R3</td>
<td>184647</td>
<td>202</td>
</tr>
</tbody>
</table>
### Table 4-1[a]. Direct Inputs (Continued)

<table>
<thead>
<tr>
<th>Line #</th>
<th>Document _ID</th>
<th>Reference Document</th>
<th>Document DIRS</th>
<th>DTN</th>
<th>DTN DIRS</th>
<th>PEF</th>
</tr>
</thead>
<tbody>
<tr>
<td>129 &lt;sup&gt;b&lt;/sup&gt;</td>
<td>MDL-NBS-HS-000021 Rev 03 AD02</td>
<td>Saturated Zone Flow and Transport Model Abstraction</td>
<td>NA</td>
<td>SN0710PASZFTMA.003_R0</td>
<td>183485</td>
<td>205, 209</td>
</tr>
<tr>
<td>130 &lt;sup&gt;b&lt;/sup&gt;</td>
<td>ANL-WIS-MD-000020 Rev 01 AD01</td>
<td>Initial Radionuclide Inventories</td>
<td>NA</td>
<td>MO0702PASTREAM.001_R0</td>
<td>179925</td>
<td>202</td>
</tr>
<tr>
<td>131 &lt;sup&gt;b&lt;/sup&gt;</td>
<td>ANL-WIS-MD-000006 Rev 02 AD01</td>
<td>Radionuclide Screening</td>
<td>177424</td>
<td>NA</td>
<td>NA</td>
<td>210</td>
</tr>
<tr>
<td>132 &lt;sup&gt;c&lt;/sup&gt;</td>
<td>ANL-EBS-MD-000003 Rev 03 AD01</td>
<td>General Corrosion and Localized Corrosion of Waste Package Outer Barrier</td>
<td>178519</td>
<td>NA</td>
<td>NA</td>
<td>212</td>
</tr>
</tbody>
</table>

**NOTES:**

- <sup>a</sup> The direct inputs indicated reflect parameter values that were corrected in TSPA-LA Model v5.005, rather than new direct inputs to the TSPA-LA Model and are therefore cited in Section 6 of the parent document. Line item numbers from Table 4-1 of the parent report are listed for these items.
- <sup>b</sup> New direct inputs are numbered starting with line 129 to 131 and are cited in Section 6[a] of this addendum.
- <sup>c</sup> Line item 132 is a new line item that captures direct input inadvertently omitted from Table 4-1 of the parent document and cited in Section 6.3.5.1.2, Equation 6.3.5-4, in the parent document.

NA–Not applicable. Either the reference document or the DTN listed is the origin for the direct input as indicated.
<table>
<thead>
<tr>
<th>Line #</th>
<th>Document ID</th>
<th>Document Title</th>
<th>Document DIRS</th>
<th>OUTPUT DTN</th>
<th>DTN DIRS</th>
<th>PEF</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>MDL-WIS-PA-000005 REV00 AD01</td>
<td>Total System Performance Assessment Model/Analysis for the License Application</td>
<td>NA</td>
<td>MO0711GENERINP.000</td>
<td>183937</td>
<td>200, 202, 204, 206, 208, 210, 211, 214, 216, 218</td>
</tr>
<tr>
<td>2</td>
<td>MDL-WIS-PA-000005 REV00 AD01</td>
<td>Total System Performance Assessment Model/Analysis for the License Application</td>
<td>NA</td>
<td>MO0707UZKDCORR.000</td>
<td>183003</td>
<td>218</td>
</tr>
<tr>
<td>3</td>
<td>MDL-WIS-PA-000005 REV00 AD01</td>
<td>Total System Performance Assessment Model/Analysis for the License Application</td>
<td>NA</td>
<td>MO0708TSPAGENT.000</td>
<td>183000</td>
<td>202</td>
</tr>
<tr>
<td>4</td>
<td>MDL-WIS-PA-000005 REV00 AD01</td>
<td>Total System Performance Assessment Model/Analysis for the License Application</td>
<td>NA</td>
<td>MO0707EMPDECAY.000</td>
<td>182995</td>
<td>202</td>
</tr>
</tbody>
</table>

NOTE: See Appendix B in the parent document and Appendix B[a] of this addendum for a complete listing of all DTNs that support the TSPA-LA Model.
INTENTIONALLY LEFT BLANK
5[a]. ASSUMPTIONS

5.1[a] NOMINAL SCENARIO CLASS
No change.

5.2[a] EARLY FAILURE SCENARIO CLASS
No change.

5.3[a] IGNEOUS SCENARIO CLASS
No change.

5.4[a] SEISMIC SCENARIO CLASS
No change.

5.5[a] HUMAN INTRUSION SCENARIO
No change.
6[a]. **TSPA-LA MODEL DESCRIPTION**

The primary goals of Section 6 of the parent document are to describe how model components and the associated submodels (illustrated on Figure 6-1 of the parent document) are integrated in the TSPA-LA Model and how the TSPA-LA Model is implemented in order to estimate the dose incurred by a reasonably maximally exposed individual due to radionuclide releases in the Nominal, Early Failure, Igneous, and Seismic Scenario Classes, and the Human Intrusion Scenario. The contents of Section 6 in large part remain unchanged from the parent document. The focus of Section 6.3 of the parent document is on the TSPA-LA Model components and submodels and includes a discussion of their implementation. Section 6.3[a] documents the changes to conceptual models and implementation required for the addendum analyses.

In addition, it should be noted that in the parent document the terms “dripping environment” and “non-dripping environment” were used interchangeably with “seeping environment” and “non-seeping environment.” The waste package (WP) groups are determined by the fraction of WP locations that are exposed to drift seepage (Section 6.1.5.3 of parent document), not drift seepage and/or drift-wall condensation. WP locations in a non-seeping environment may be exposed to dripping as a result of drift-wall condensation. When reading the parent document the term “dripping environment” should be replaced with the term “seeping environment” and the term “non-dripping environment” should be replaced with the term “non-seeping environment.”

6.1[a] **CONCEPTUAL DESIGN**

No change.

6.1.1[a] **Features, Events, and Processes Screening and Scenario Development**

No change.

6.1.2[a] **Calculation of Dose for the TSPA-LA Model**

This section of the parent document outlines the calculation of total mean annual dose and total median annual dose using the scenario classes defined in Section 6.1.1 of the parent document. Specifically, Section 6.1.2.4 of the parent document describes calculations for each of the individual modeling cases used in the TSPA-LA Model. Section 6.1.2.4.2 has been updated to include additional information inadvertently omitted from the parent document which is relevant to the calculations for the expected annual dose for the Early Failure Modeling Cases. Section 6.1.2.4.2[a] in this addendum contains the additional information which should be used in conjunction with the documentation provided in the parent document. Appendix J of the parent document presents formal derivations for calculation of total mean annual dose and total median annual dose and the calculations performed for each modeling case. Appendix J[a] includes additional supplemental background discussion about the conceptual structure of the TSPA-LA Model calculations.

6.1.2.1[a] **Description of Uncertainty**

No change.
6.1.2.2[a] Calculation of Total Mean Annual Dose

No change.

6.1.2.3[a] Screening of Scenario Classes

No change.

6.1.2.4[a] Calculation of Expected Annual Dose for the Modeling Cases

Section 6.1.2.4.2[a] includes additional information inadvertently omitted from the parent document which is relevant to the calculations for the expected annual dose for the Early Failure Modeling Cases.

6.1.2.4.1[a] Nominal Scenario Class

No change.

6.1.2.4.2[a] Early Failure Scenario Class

The calculation of expected annual dose for the Waste Package and Drip Shield EF Modeling Case is defined in Equation 6.1.2-13 and Equation 6.1.2-14 of the parent document. In both the Waste Package EF and Drip Shield EF Modeling Cases, aleatory uncertainty in the location of the early failed WP within its assigned percolation bin is implicitly considered by assigning the mass released from the WP uniformly across the bin. The uniform mass release is implemented by distributing the mass released by the WP equally to all the UZ particle tracking model’s repository release nodes (Section 6.3.9.3) associated with the specific percolation bin. The definitions of $D_{EW} \left( \tau \left[1, r, s, t \right], \mathbf{e}_r \right)$ and $D_{ED} \left( \tau \left[1, r, s, t \right], \mathbf{e}_r \right)$ are modified accordingly:

$$D_{EW} \left( \tau \left[1, r, s, t \right], \mathbf{e}_r \right)$$

is the dose at time $\tau$ that results from early failure of one WP of type $r$ in percolation bin $s$ with seeping ($t = 1$) or non-seeping conditions ($t = 0$), where release from the WP is distributed uniformly over the UZ repository release nodes for percolation bins. This quantity is calculated using the GoldSim component of the TSPA-LA Model.

and,

$$D_{ED} \left( \tau \left[1, r, s, t \right], \mathbf{e}_r \right)$$

is the dose at time $\tau$ that results from early failure of one drip shield (DS) over a WP of type $r$ in percolation bin $s$ with seeping ($t = 1$) or non-seeping conditions ($t = 0$), where release from the WP is distributed uniformly over the UZ repository release nodes for percolation bin $s$. This quantity is calculated using the GoldSim component of the TSPA-LA Model.

6.1.2.4.3[a] Igneous Scenario Class

No change.
6.1.2.4[a] Seismic Scenario Class

No change.

6.1.2.5[a] Calculation of Expected Annual Dose for the Human Intrusion Modeling Case

No change.

6.1.3[a] Treatment of Uncertainty in the TSPA-LA Model

No change.

6.1.4[a] TSPA-LA Model Structure and Design

This section in the parent document provides an overview of how model components and submodels are connected within the TSPA-LA Model and how information flows between them. The primary focus of this section is on the description of the TSPA-LA Model for the Nominal Scenario Class. This addendum contains an update that incorporates additional information about the TSPA-LA Model structure and information flow documented in Section 6.1.4.2 of the parent document. In addition, Figure 6.1.4-5 from the parent document has been revised to correct an error in the original figure and is included as Figure 6.1.4-5[a].

6.1.4.1[a] Mountain-Scale Unsaturated Zone Flow

No change.

6.1.4.2[a] Engineered Barrier System Thermal-Hydrologic Environment

In the parent document, the fourth bullet of Output 3, Information Transfer from the EBS TH Environment Submodel to the Drift Seepage and Drift Wall Condensation Submodels, omitted the transfer of information pertaining to drift-wall condensation Stage 2 and Stage 3 start times. This addendum includes the correction for this omission.

Output 3—The following outputs are passed from the EBS TH Environment Submodel (Section 6.3.2) to the Drift Seepage and Drift Wall Condensation Submodel (Section 6.3.3):

- For each of the five percolation subregions (Section 6.3.2):
  - The percolation flux at the base of the PTn for each infiltration scenario and climate at each multiscale thermohydrologic model subdomain location (Drift Seepage Submodel)
  - The average percolation flux at the base of the PTn for each infiltration scenario and climate (Drift Wall Condensation Submodel)
  - The drift-wall temperature surrounding each of the eight WPs (two co-disposed [CDSP] WPs and six CSNF WPs) at each subdomain location (Drift Seepage Submodel)
- Time-dependent temperature for the drift wall and WP for the representative CDSP WP and the representative CSNF WP, including the time that these temperatures drop to 96°C (Drift Wall Condensation Submodel)

- The fraction of lithophysal unit at each location.
Figure 6.1.4-5[a]. Information Transfer between the Submodels of the TSPA-LA Volcanic Eruption Modeling Case
6.1.5[a] TSPA-LA Model File Architecture

In addition to the issues that have been addressed in the updated TSPA-LA Model v5.005 model file for this addendum, an additional cosmetic change was made to TSPA-LA Model v5.005. This change was the reorganization of the elements within the model, primarily adding clarity and traceability. As a result, some model pathways identified in Table 6.1.5-1 have changed. Table 6.1.5-1[a] provides an updated summary of the locations of submodel documentation within the GoldSim model file.
INTENTIONALLY LEFT BLANK
Table 6.1.5-1[a]. Location of Implementation Description in the GoldSim TSPA-LA Model File

<table>
<thead>
<tr>
<th>Submodel</th>
<th>Documentation Location(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epistemic Parameters GoldSim Submodel</td>
<td>\Epistemic_Uncertainty\Epistemic_Params</td>
</tr>
<tr>
<td>Aleatory Parameters and Dynamic</td>
<td>\Time_Zero\Aleatory_Params</td>
</tr>
<tr>
<td>Calculations GoldSim Submodel</td>
<td></td>
</tr>
<tr>
<td>EBS GoldSim Submodel</td>
<td>\Time_Zero\EBS_PS_Loop\EBS_PSE_Loop\EBS_Submodel</td>
</tr>
<tr>
<td>Natural System below the Repository</td>
<td>\TSPA_Model</td>
</tr>
<tr>
<td>Climate</td>
<td>Epistemic: NA</td>
</tr>
<tr>
<td></td>
<td>Aleatory: NA</td>
</tr>
<tr>
<td></td>
<td>EBS: \Global_Inputs_and_Calcs\Global_UZ_Flow\Climate</td>
</tr>
<tr>
<td></td>
<td>Other: \TSPA_Model\UZ_Flow\Climate</td>
</tr>
<tr>
<td>Infiltration</td>
<td>Epistemic: \Input_Params_Epistemic\Epistemic_Params_UZ_Flow\Uncert</td>
</tr>
<tr>
<td></td>
<td>Aleatory: NA</td>
</tr>
<tr>
<td></td>
<td>EBS: \Time_Zero\EBS_PS_Loop\Static_Calcs\PS_Loop\Static_Calcs\UZ_Flow\Infiltration</td>
</tr>
<tr>
<td></td>
<td>\Global_Inputs_and_Calcs\Global_UZ_Flow\Infiltration</td>
</tr>
<tr>
<td>Drift Seepage</td>
<td>Epistemic: \Input_Params_Epistemic\Epistemic_Params_UZ_Flow\Input_Params_Seepage\Uncert</td>
</tr>
<tr>
<td></td>
<td>Aleatory: NA</td>
</tr>
<tr>
<td></td>
<td>EBS: \Time_Zero\EBS_PS_Loop\Static_Calcs\PS_Loop\Static_Calcs\UZ_Flow\Drift_Seepage</td>
</tr>
<tr>
<td></td>
<td>\Global_Inputs_and_Calcs\Global_UZ_Flow\Drift_Seepage</td>
</tr>
<tr>
<td>Drift Wall Condensation</td>
<td>Epistemic: \Input_Params_Epistemic\Epistemic_Params_UZ_Flow\Uncert_Params_DWC</td>
</tr>
<tr>
<td></td>
<td>Aleatory: NA</td>
</tr>
<tr>
<td></td>
<td>EBS: \Global_Inputs_and_Calcs\Global_UZ_Flow\Drift_Wall\Condensation</td>
</tr>
<tr>
<td>EBS TH Environment</td>
<td>Epistemic: \Input_Params_Epistemic\Epistemic_Params_EBS_Environment\Uncert_Params_TH</td>
</tr>
<tr>
<td></td>
<td>Aleatory: NA</td>
</tr>
<tr>
<td></td>
<td>EBS: \Global_Inputs_and_Calcs\Global_EBS_Environment\Thermo\Hydrology</td>
</tr>
<tr>
<td>WP and DS Degradation</td>
<td>Epistemic: \Input_Params_Epistemic\Epistemic_Params_WP_DS_Deg</td>
</tr>
<tr>
<td></td>
<td>Aleatory: \Model_Calcs\Aleatory\Aleatory_Calcs\WP_DS_Deg</td>
</tr>
<tr>
<td></td>
<td>EBS: \Time_Zero\EBS_PS_Loop\Static_Calcs\PS_Loop\Static_Calcs\WP_DS_Deg</td>
</tr>
<tr>
<td></td>
<td>\Global_Inputs_and_Calcs\Global_WP_DS_Deg\Global_WP_PD</td>
</tr>
<tr>
<td>Localized Corrosion</td>
<td>Epistemic: \Input_Params_Epistemic\Epistemic_Params_WP_DS_Deg</td>
</tr>
<tr>
<td></td>
<td>Aleatory: NA</td>
</tr>
<tr>
<td></td>
<td>EBS: \Time_Zero\EBS_PS_Loop\Static_Calcs\PS_Loop\Static_Calcs\WP_DS_Deg</td>
</tr>
<tr>
<td></td>
<td>\Global_Inputs_and_Calcs\Global_WP_DS_Deg\Global_LC</td>
</tr>
</tbody>
</table>
### Table 6.1.5-1[a]. Location of Implementation Description in the GoldSim TSPA Model File (Continued)

<table>
<thead>
<tr>
<th>Submodel</th>
<th>Documentation Location(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radionuclide Inventory</td>
<td>Epistemic: \Input_Params_Epistemic\Epistemic_Params_WF_Deg_Mob\Uncertain_Params_RN_Inventor&lt;br&gt;Aleatory: NA&lt;br&gt;EBS: \Global_Inputs_and_Calcs\Global_WF_Deg_Mob\RN_Inventory</td>
</tr>
<tr>
<td>In-Package Chemistry</td>
<td>Epistemic: \Input_Params_Epistemic\Epistemic_Params_WF_Deg_Mob\Uncertain_Params_InPkg_Chem&lt;br&gt;Aleatory: NA&lt;br&gt;EBS: \Global_Inputs_and_Calcs\Global_WF_Deg_Mob\In_Package_Chemistry</td>
</tr>
<tr>
<td>Waste Form Degradation</td>
<td>Epistemic: \Input_Params_Epistemic\Epistemic_Params_WF_Deg_Mob\Uncertain_Params_CSNF_WF&lt;br&gt;Aleatory: NA&lt;br&gt;EBS: \Global_Inputs_and_Calcs\Global_WF_Deg_Mob\WF_Degradation\CSNF_WF_Dissolution&lt;br&gt;Epistemic: \Input_Params_Epistemic\Epistemic_Params_WF_Deg_Mob\Uncertain_Params_HLW_WF&lt;br&gt;Aleatory: NA&lt;br&gt;EBS: \Global_Inputs_and_Calcs\Global_WF_Deg_Mob\WF_Degradation\Input_Params_HLW_WF&lt;br&gt;Epistemic: NA&lt;br&gt;Aleatory: NA&lt;br&gt;EBS: \Global_Inputs_and_Calcs\Global_WF_Deg_Mob\WF_Degradation\Input_Params_DSNF_WF</td>
</tr>
<tr>
<td>EBS Chemical Environment</td>
<td>Epistemic: \Input_Params_Epistemic\Epistemic_Params_EBS_Environ\Uncertain_Params_EBS_CE&lt;br&gt;Aleatory: \Input_Params_Aleatory\Input_Params_EBS_Environ\Input_Params_EBS_CE&lt;br&gt;EBS: \Global_Inputs_and_Calcs\Global_EBS_Environ\EBS_Chemical_Environment</td>
</tr>
<tr>
<td>Dissolved Concentration Limits</td>
<td>Epistemic: \Input_Params_Epistemic\Epistemic_Params_WF_Deg_Mob\Uncertain_Params_Solubility&lt;br&gt;Aleatory: NA&lt;br&gt;EBS: \Global_Inputs_and_Calcs\Global_WF_Deg_Mob\Global_Solubility</td>
</tr>
<tr>
<td>EBS Colloids</td>
<td>Epistemic: \Input_Params_Epistemic\Epistemic_Params_EBS_F_and_T\Uncertain_Params_Colloids&lt;br&gt;Aleatory: NA&lt;br&gt;EBS: \Global_Inputs_and_Calcs\Global_EBS_F_and_T\Model_Input_EBS_Transport\Input_Params_Colloids</td>
</tr>
</tbody>
</table>
Table 6.1.5-1[a]. Location of Implementation Description in the GoldSim TSPA Model File (Continued)

<table>
<thead>
<tr>
<th>Submodel</th>
<th>Documentation Location(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EBS Flow</td>
<td>Epistemic: \Input_Params_Epistemic\Epistemic_Params_EBS_F_and_T\Uncertain_Params_Flux_Split</td>
</tr>
<tr>
<td></td>
<td>Aleatory: NA</td>
</tr>
<tr>
<td></td>
<td>EBS: \Global_Inputs_and_Calcs\Global_EBS_F_and_T\Model_Feeds_EBS_Flow</td>
</tr>
<tr>
<td>EBS Transport</td>
<td>Epistemic: \Input_Params_Epistemic\Epistemic_Params_EBS_F_and_T</td>
</tr>
<tr>
<td></td>
<td>Aleatory: NA</td>
</tr>
<tr>
<td></td>
<td>EBS: \Global_Inputs_and_Calcs\Global_EBS_F_and_T\Model_Input_EBS_Transport</td>
</tr>
<tr>
<td>EBS-UZ Interface</td>
<td>Epistemic: \Input_Params_Epistemic\Epistemic_Params_EBS_F_and_T\Uncertain_Params_EBS_UZ_Trans</td>
</tr>
<tr>
<td></td>
<td>Aleatory: NA</td>
</tr>
<tr>
<td></td>
<td>EBS: \Global_Inputs_and_Calcs\Global_EBS_F_and_T\EBS_UZ_Transport_Inputs</td>
</tr>
<tr>
<td>UZ Transport</td>
<td>Epistemic: \Input_Params_Epistemic\Epistemic_Params_UZ_Transport</td>
</tr>
<tr>
<td></td>
<td>Aleatory: NA</td>
</tr>
<tr>
<td></td>
<td>Other: \TSPA_Model\UZ_Transport</td>
</tr>
<tr>
<td>SZ Flow and Transport</td>
<td>Epistemic: \Input_Params_Epistemic\Epistemic_Params_SZ_Transport</td>
</tr>
<tr>
<td></td>
<td>Aleatory: NA</td>
</tr>
<tr>
<td></td>
<td>Other: \TSPA_Model\SZ_Transport</td>
</tr>
<tr>
<td>Biosphere</td>
<td>Epistemic: \Input_Params_Epistemic\Epistemic_Params_Biosphere</td>
</tr>
<tr>
<td></td>
<td>Aleatory: NA</td>
</tr>
<tr>
<td></td>
<td>Other: \TSPA_Model\Biosphere</td>
</tr>
<tr>
<td>Early Failure Scenario Class</td>
<td>Epistemic: \Input_Params_Epistemic\Epistemic_Params_Events\Epistemic_Parameters_EF</td>
</tr>
<tr>
<td></td>
<td>Aleatory: \Input_Params_Aleatory\Aleatory_Params_Events\Aleatory_Params_EF</td>
</tr>
<tr>
<td></td>
<td>EBS: \Time_Zero\EBS_PS_Loop\Static_Calcs_PS_Loop\Static_Calcs_Events\Static_Calcs_EF</td>
</tr>
<tr>
<td></td>
<td>\Global_Inputs_and_Calcs\Global_Events\Global_EF</td>
</tr>
<tr>
<td>Igneous Scenario Class</td>
<td>Epistemic: \Input_Params_Epistemic\Epistemic_Params_Events\Epistemic_Params_Igneous_Intr</td>
</tr>
<tr>
<td></td>
<td>Aleatory: \Input_Params_Aleatory\Aleatory_Params_Events\Aleatory_Params_Igneous_Intr</td>
</tr>
<tr>
<td></td>
<td>EBS: \Time_Zero\EBS_PS_Loop\Static_Calcs_PS_Loop\Static_Calcs_Events\Igneous_Intrusion</td>
</tr>
<tr>
<td></td>
<td>\Global_Inputs_and_Calcs\Global_Events\Igneous_Scenario</td>
</tr>
<tr>
<td></td>
<td>Epistemic: \Model_Uncertainties\EU</td>
</tr>
<tr>
<td></td>
<td>Aleatory: \Model_Uncertainties\AU</td>
</tr>
<tr>
<td></td>
<td>EBS: \Eruptive_Model</td>
</tr>
</tbody>
</table>
Table 6.1.5-1[a]. Location of Implementation Description in the GoldSim TSPA Model File (Continued)

<table>
<thead>
<tr>
<th>Submodel</th>
<th>Documentation Location(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seismic Scenario Class</td>
<td>Epistemic: \Input_Params_Epistemic\Epistemic_Params_Events\Epistemic_Params_Seismic \Input_Params_Aleatory\Aleatory_Params_Events\Input_Params_Seismic_Uncert \Input_Params_Aleatory\Aleatory_Params_Events\Input_Params_Seismic_FD_Uncert</td>
</tr>
<tr>
<td></td>
<td>EBS: \Time_Zero\EBS_PS_Loop\Static_Calcs_PS_Loop\Static_Calcs_Events\Seismic_Scenario_Class \Time_Zero\EBS_PS_Loop\Static_Calcs_PS_Loop\Static_Calcs_Events\Seismic_Fault_Displacement \Global_Inputs_and_Calcs\Global_Events\Seismic_Scenario</td>
</tr>
<tr>
<td>Human Intrusion Scenario</td>
<td>Epistemic: NA \Input_Params_Aleatory\Aleatory_Params_Events\Aleatory_Params_HI</td>
</tr>
<tr>
<td></td>
<td>EBS: \Time_Zero\EBS_PS_Loop\Static_Calcs_PS_Loop\Static_Calcs_Events\Seismic_Scenario_Class \Time_Zero\EBS_PS_Loop\Static_Calcs_PS_Loop\Static_Calcs_Events\Seismic_Fault_Displacement \Global_Inputs_and_Calcs\Global_Events\Seismic_Scenario</td>
</tr>
<tr>
<td></td>
<td>Other: \TSPA_Model\UZ_Transport\UZ_Transport_Calculations\HI_Borehole_Transport</td>
</tr>
</tbody>
</table>
6.2[a] ALTERNATIVE CONCEPTUAL MODELS

No change.

6.3[a] TSPA-LA MODEL FOR THE NOMINAL SCENARIO CLASS

This section presents an updated description of the Nominal Scenario Class in support of the analyses of the TSPA-LA Model presented in this addendum (output DTN: MO0710ADTSPAWI.000 [DIRS 183751]). This addendum describes only additions or changes to the conceptual models, model abstractions, and implementation of these abstractions in the TSPA-LA Model that were necessary to support the analyses presented in this addendum. It also provides a description of amendments to the following subsections of the parent document:

- Section 6.3.2, Engineered Barrier System Thermal-Hydrologic Environment
- Section 6.3.3, Drift-Scale Unsaturated Zone Flow
- Section 6.3.7, Waste Form Degradation and Mobilization
- Section 6.3.8, Engineered Barrier System Transport
- Section 6.3.9, Unsaturated Zone Transport
- Section 6.3.10, Saturated Zone Flow and Transport Model Component.

The focus of this section is on the updated TSPA-LA Model components and submodels and their implementation for the Nominal Scenario Class.

6.3.1[a] Mountain-Scale Unsaturated Zone Flow

No change.

6.3.2[a] Engineered Barrier System Thermal-Hydrologic Environment

Section 6.3.2.3[a] includes supplemental material to be used in conjunction with the discussion documented in Section 6.3.2.3 of the parent document. The material was inadvertently omitted from Section 6.3.2.3 of the parent document and does not reflect a change in the EBS Thermal-Hydrologic (TH) Environment conceptual model, abstraction, or implementation in the TSPA-LA Model. In addition, the caption for Figure 6.3.2-7 in the parent document has been corrected and is included as Figure 6.3.2-7[a] of this addendum.

6.3.2.1[a] Conceptual Model

No change.

6.3.2.2[a] Model Abstraction

No change.
6.3.2.3[a] TSPA-LA Model Implementation

Section 6.3.2.3[a] has been modified to include an additional sentence that clarifies the details of the EBS TH Environment Submodel implementation in the TSPA-LA Model.

The following text should be added to the third paragraph of Section 6.3.2.3 of the parent document:

The ten representative TH histories applied to the WP groups in the TSPA-LA Model closely matched the median history of a large group of waste packages that, as modeled, included the effects of percolation, dry out, and rewetting of the host rock above the repository. As such, the history is expected to be representative of a WP whether it is exposed to seepage or not.

6.3.2.4[a] Model Component Consistency and Conservatism in Assumptions and Parameters

No change.

6.3.2.5[a] Alternative Conceptual Model(s) for the Engineered Barrier System Thermal-Hydrologic Environment

No change.
Source: SNL 2007 [DIRS 181383], Figure VIII-1[a].

Figure 6.3.2-7[a]. Repository Percolation Subregions Used in the TSPA-LA Model (based upon the 10th percentile infiltration scenario, glacial-transition period)
INTENTIONALLY LEFT BLANK
6.3.3[a]  Drift-Scale Unsaturated Zone Flow

The analyses documented in this addendum include an update of the seepage fraction for the 10,000-year regulatory time period from that used in the analyses documented in the parent document (Appendix P, Section P2, of the parent document). The following text details the amendments to the Drift-Scale Unsaturated Zone Flow Submodel implementation in support of the analyses documented in this addendum.

6.3.3.1.1[a]  Conceptual Model

No change.

6.3.3.1.2[a]  TSPA-LA Model Abstraction

No change.

6.3.3.1.3[a]  TSPA-LA Model Implementation

The TSPA-LA Model implementation of drift seepage is primarily accomplished through the use of an external dynamically linked library. Drift-seepage submodel calculations in the TSPA-LA Model are conducted by the SEEPAGEDLL_LA (STN: 11076-1.3-01 [DIRS 181058]). Section 6.3.3.1.3 of the parent document describes the drift-seepage implementation in detail. The calculation of the seepage rates is comprised of two main steps: (1) evaluate ambient seepage rate from seepage look-up tables, and (2) adjust ambient seepage rate for thermal and drift degradation effects. This approach remains unchanged in the analyses documented in this addendum. The calculation of the seepage fraction for the addendum is determined as outlined in Step 3 below and differs slightly from that of the parent document.

Step 3: Determination of Seepage Fraction for the TSPA-LA Addendum Analyses

For the analyses documented in this addendum, the seepage fractions for the 10,000-year simulations are based on the glacial-transition climate. The seepage fraction is the fraction of WPs, by type, in a percolation subregion that experiences seepage in a given realization. Although the projections of the expected annual dose to the reasonably maximally exposed individual that are compared to the 10,000-year Individual Protection Standard (NRC Proposed Rule 10 CFR 63.311 [DIRS 178394]) in Section 8.2[a] are extracted from the 20,000-year simulations, the seepage fraction is determined as the fraction of WPs that experiences seepage at any time during the first 10,000 years, instead of over the entire 20,000-year period as calculated in the parent document. The seepage fraction is calculated, as described in Section 6.3.3.1.3 of the parent document, by using a threshold seepage rate of 0.1 kg/yr per WP. WPs with seepage at any time are in a seep environment, and those without seepage are in a non-seep environment as evaluated during the 10,000-year regulatory period. The seepage fractions used for the additional analyses documented in this addendum for the 1,000,000-year simulations are identical to those described in the parent document.

6.3.4[a]  Engineered Barrier System Chemical Environment

No change.
6.3.5[a] Waste Package and Drip Shield Degradation

Section 6.3.5.1.3[a] includes supplemental material that should be used in conjunction with the discussion documented in Section 6.3.5.1.3 of the parent document. The material was inadvertently omitted from Section 6.3.5.1.3 of the parent document and does not reflect a change in the WP and DS degradation conceptual model, abstraction, or implementation in the TSPA-LA Model.

6.3.5.1[a] Waste Package and Drip Shield Degradation

Section 6.3.5.1.3[a] has been modified to include an additional paragraph that details the implementation for both incipient and weld flaw crack penetration in a closure-lid patch for WPs in the TSPA-LA Model.

6.3.5.1.1[a] Conceptual Model

No change.

6.3.5.1.2[a] Abstraction of Waste Package and Drip Shield Degradation

No Change.

6.3.5.1.3[a] Implementation in the TSPA-LA Model

The following paragraph should follow the last paragraph in this section of the parent document and be used to supplement the material presented in parent document Section 6.3.5.1.3, under the subheading WP and DS Degradation Submodel Output.

WP and DS Degradation Submodel Output

Stress corrosion cracking can be initiated on an outer barrier closure-lid patch as the result of incipient cracks and weld flaws (Section 6.3.5.1.2 of the parent document). The incipient cracks are present on all lid patches (six cracks per patch with an initial length of 0.05 mm) (Section 6.3.5.1.2 of the parent document). Weld flaws are far less frequent (Equation 6.3.5-12 of the parent document). For a given patch, all incipient cracks grow at the same rate so they penetrate at the same time. The WAPDEG V4.07 (STN: 10000-4.07-00 [DIRS 181774] and STN: 10000-4.07-01 [DIRS 181064]) software tracks only one crack per patch so that the output for the crack area is scaled up by a factor of six to account for the true density of incipient cracks. If the first crack penetration on a closure-lid patch is due to a weld flaw then the scale up is conservative because the probability of 2 or more weld flaws per patch is very small (Equation 6.3.5-12 of the parent document).

6.3.5.2[a] Localized Corrosion on the Waste Package Outer Surface

No change.
6.3.5.3[a] Model Component Consistency and Conservatism in Assumptions and Parameters

No change.

6.3.5.4[a] Alternative Conceptual Model(s) for Waste Package and Drip Shield Degradation

No change.

6.3.6[a] Engineered Barrier System Flow

Figure 6.3.6-3[a] has been revised from the parent document to illustrate a representation of a typical emplacement drift according to the current design.
INTENTIONALLY LEFT BLANK
Figure 6.3.6-3[a]. Illustrative Cross Section of a Typical Emplacement Drift
INTENTIONALLY LEFT BLANK
6.3.7[a] Waste Form Degradation and Mobilization

Table 6.3.7-6[a] contains an update to the summary of the treatment of each radionuclide within the SZ Transport Submodel (Section 6.3.10[a]) and the Biosphere Submodel (Section 6.3.11) for the groundwater release modeling cases. In addition, Table 6.3.7-64[a] contains an update to correct the distribution coefficient for reversible sorption of neptunium onto uranophane colloids, incorrectly implemented as 1 to 5 × 10² (Appendix P[a], Table P-6[a], Item 8).
INTENTIONALLY LEFT BLANK
Table 6.3.7-6[a]. Disposition of Radionuclides for Groundwater Release Modeling Cases: Nominal, Igneous Intrusion, and Seismic

<table>
<thead>
<tr>
<th>Radionuclide (Table 6.3.7-2)</th>
<th>Disposition in Waste Form, EBS, and UZ TSPA-LA Model Components (Section 6.3.7)</th>
<th>Disposition in 3-D UZ FEHM Submodel(^a) (Section 6.3.9)</th>
<th>Disposition in SZ Submodels (3-D SZ_Convolute and 1-D Pipe)(^b) (Section 6.3.10 and 6.3.10[a])</th>
<th>Disposition in Biosphere (Section 6.3.11)</th>
</tr>
</thead>
<tbody>
<tr>
<td>227Ac</td>
<td>Not transported</td>
<td>Not transported</td>
<td>Dose from 3-D and 1-D, assuming secular equilibrium with 231Pa</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>241Am</td>
<td>Transport embedded colloid 241Am(_{emb}) (decay to 237Np)</td>
<td>Transport slow irreversible colloid 241Am(_{irs}) (decay to 237Np)</td>
<td>3-D transport of americium/plutonium slow irreversible colloid [SZ BTC 6]</td>
<td>Dose from 3-D</td>
</tr>
<tr>
<td></td>
<td>Transport irreversible FeO colloid 241Am(_{FeO}) (decay to 237Np)</td>
<td>Transport fast irreversible colloid 241Am(_{fri}) (decay to 237Np)</td>
<td>3-D transport of americium/plutonium fast irreversible colloid [SZ BTC 10]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Transport reversible colloid and solute (decay to 237Np)</td>
<td>Transport reversible colloid and solute (decay to 237Np)</td>
<td>3-D transport of americium/thorium/protactinium reversible colloid and solute [SZ BTC 2]</td>
<td></td>
</tr>
<tr>
<td>243Am</td>
<td>Transport embedded colloid 243Am(<em>{emb}) (decay to 239Pu(</em>{emb}))</td>
<td>Transport slow irreversible colloid 243Am(<em>{irs}) (decay to 239Pu(</em>{irs}))</td>
<td>3-D transport of americium/plutonium slow irreversible colloid [SZ BTC 6]</td>
<td>Dose from 3-D</td>
</tr>
<tr>
<td></td>
<td>Transport irreversible FeO colloid 243Am(<em>{FeO}) (decay to 239Pu(</em>{FeO}))</td>
<td>Transport fast irreversible colloid 243Am(<em>{fri}) (decay to 239Pu(</em>{fri}))</td>
<td>3-D transport of americium/plutonium fast irreversible colloid [SZ BTC 10]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Transport reversible colloid and solute (decay to 239Pu)</td>
<td>Transport reversible colloid and solute (decay to 239Pu)</td>
<td>3-D transport of americium/thorium/protactinium reversible colloid and solute [SZ BTC 2]</td>
<td></td>
</tr>
<tr>
<td>14C</td>
<td>Transport solute</td>
<td>Transport solute</td>
<td>3-D transport of nonsorbing solute [SZ BTC 1]</td>
<td>Dose from 3-D</td>
</tr>
<tr>
<td>36Cl</td>
<td>Transport solute</td>
<td>Transport solute</td>
<td>3-D transport of nonsorbing solute [SZ BTC 1]</td>
<td>Dose from 3-D</td>
</tr>
<tr>
<td>245Cm(^d)</td>
<td>Not transported (decay to 241Pu)</td>
<td>Not transported</td>
<td>Not transported</td>
<td>Dose not computed</td>
</tr>
<tr>
<td>135Cs</td>
<td>Transport reversible colloid and solute</td>
<td>Transport reversible colloid and solute</td>
<td>3-D transport of cesium reversible colloid and solute [SZ BTC3]</td>
<td>Dose from 3-D</td>
</tr>
<tr>
<td>137Cs</td>
<td>Transport reversible colloid and solute</td>
<td>Transport reversible colloid and solute</td>
<td>3-D transport of cesium reversible colloid and solute [SZ BTC 3]</td>
<td>Dose from 3-D</td>
</tr>
<tr>
<td>129I</td>
<td>Transport solute</td>
<td>Transport solute</td>
<td>3-D transport of nonsorbing solute [SZ BTC 1]</td>
<td>Dose from 3-D</td>
</tr>
<tr>
<td>237Np</td>
<td>Transport reversible colloid and solute (decay to 233U)</td>
<td>Transport solute (decay to 233U)</td>
<td>3-D transport of neptunium solute [SZ BTC 5], boosted(^e) by 241Am(<em>{irs}), 241Am(</em>{fri}), and 241Am(_{rev/sol})</td>
<td>Dose from 3-D</td>
</tr>
</tbody>
</table>
Table 6.3.7-6[a]. Disposition of Radionuclides for Groundwater Release Modeling Cases: Nominal, Igneous Intrusion, and Seismic (Continued)

<table>
<thead>
<tr>
<th>Radionuclide (Table 6.3.7-2)</th>
<th>Disposition in Waste Form, EBS, and UZ TSPA-LA Model Components (Section 6.3.7)</th>
<th>Disposition in 3-D UZ FEHM Submodel(^a) (Section 6.3.9)</th>
<th>Disposition in SZ Submodels (3-D SZ_Convolute and 1-D Pipe)(^b) (Section 6.3.10 and 6.3.10[a])</th>
<th>Disposition in Biosphere (Section 6.3.11)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{231}$Pa</td>
<td>Transport reversible colloid and solute (decay to $^{227}$Ac)</td>
<td>Transport reversible colloid and solute (simple decay)</td>
<td>3-D transport of reversible colloid and solute (decay to $^{227}$Ac) [SZ BTC 2] 1-D transport only the mass created by ingrowth from $^{235}$U decay</td>
<td>Dose from 3-D and 1-D</td>
</tr>
<tr>
<td>$^{210}$Pb(^g)</td>
<td>Not explicitly included</td>
<td>Not explicitly included</td>
<td>Not explicitly included</td>
<td>Dose included with $^{226}$Ra BDCF(^a)</td>
</tr>
<tr>
<td>$^{238}$Pu</td>
<td>Transport embedded colloid $^{238}$Pu(_{emb}) (decay to $^{234}$U)</td>
<td>Transport slow irreversible colloid $^{238}$Pu(_{irs}) (decay to $^{234}$U)</td>
<td>3-D transport of americium/plutonium slow irreversible colloid [SZ BTC 6] 3-D transport of americium/plutonium fast irreversible colloid [SZ BTC 10] 3-D transport of plutonium reversible colloid [SZ-BTC 4]</td>
<td>Dose from 3-D</td>
</tr>
<tr>
<td></td>
<td>Transport irreversible FeO colloid $^{238}$Pu(_{FeO}) (decay to $^{234}$U)</td>
<td>Transport fast irreversible colloid $^{238}$Pu(_{irf}) (decay to $^{234}$U)</td>
<td>Dose from 3-D(^g)</td>
<td></td>
</tr>
<tr>
<td>$^{239}$Pu</td>
<td>Transport embedded colloid $^{239}$Pu(_{emb}) (decay to $^{235}$U)</td>
<td>Transport slow irreversible colloid $^{239}$Pu(_{irs}) (decay to $^{235}$U)</td>
<td>3-D transport of americium/plutonium slow irreversible colloid [SZ BTC 6], boosted(^c) by $^{243}$Am(<em>{irs}) 3-D transport of americium/plutonium fast irreversible colloid [SZ BTC 10], boosted(^c) by $^{243}$Am(</em>{irf}) 3-D transport of plutonium reversible colloid [SZ-BTC 4], boosted(^c) by $^{243}$Am(_{rev/sol})</td>
<td>Dose from 3-D</td>
</tr>
<tr>
<td></td>
<td>Transport irreversible FeO colloid $^{239}$Pu(_{FeO}) (decay to $^{235}$U)</td>
<td>Transport fast irreversible colloid $^{239}$Pu(_{irf}) (decay to $^{235}$U)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Transport reversible colloid and solute (decay to $^{235}$U)</td>
<td>Transport reversible colloid and solute (decay to $^{235}$U)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$^{240}$Pu</td>
<td>Transport embedded colloid Pu(_{emb}) (decay to $^{236}$U)</td>
<td>Transport slow irreversible colloid $^{240}$Pu(_{irs}) (decay to $^{236}$U)</td>
<td>3-D transport of americium/plutonium slow irreversible colloid [SZ BTC 6] 3-D transport of americium/plutonium fast irreversible colloid [SZ BTC 10] 3-D transport of plutonium reversible colloid [SZ BTC 4]</td>
<td>Dose from 3-D</td>
</tr>
<tr>
<td></td>
<td>Transport irreversible FeO colloid $^{240}$Pu(_{FeO}) (decay to $^{236}$U)</td>
<td>Transport fast irreversible colloid $^{240}$Pu(_{irf}) (decay to $^{236}$U)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Transport reversible colloid and solute (decay to $^{236}$U)</td>
<td>Transport reversible colloid and solute (decay to $^{236}$U)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$^{241}$Pu(^d)</td>
<td>Not transported (decay to $^{241}$Am)</td>
<td>Not transported</td>
<td>Not transported</td>
<td>Dose not computed</td>
</tr>
<tr>
<td>Radionuclide (Table 6.3.7-2)</td>
<td>Disposition in Waste Form, EBS, and UZ TSPA-LA Model Components (Section 6.3.7)</td>
<td>Disposition in 3-D UZ FEHM Submodela (Section 6.3.9)</td>
<td>Disposition in SZ Submodels (3-D SZ_Convolute and 1-D Pipe)b (Section 6.3.10 and 6.3.10[a])</td>
<td>Disposition in Biosphere (Section 6.3.11)</td>
</tr>
<tr>
<td>---------------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------</td>
<td>-------------------------------------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------</td>
<td>-----------------------------------------</td>
</tr>
<tr>
<td>$^{242}$Pu</td>
<td>Transport embedded colloid $^{242}$Pu$_{emb}$ (decay to $^{238}$U)</td>
<td>Transport slow irreversible colloid $^{242}$Pu$<em>{irs}$ (decay to $^{238}$U)  &lt;br&gt; Transport fast irreversible colloid $^{242}$Pu$</em>{irf}$ (decay to $^{238}$U)  &lt;br&gt; Transport reversible colloid and solute (decay to $^{238}$U)</td>
<td>3-D transport of americium/plutonium slow irreversible colloid [SZ BTC 6]  &lt;br&gt; 3-D transport of americium/plutonium fast irreversible colloid [SZ BTC 10]  &lt;br&gt; 3-D transport of plutonium reversible colloid and solute [SZ BTC 4]</td>
<td>Dose from 3-Df</td>
</tr>
<tr>
<td>$^{226}$Ra</td>
<td>Transport reversible colloid and solute (simple decay)</td>
<td>Transport solute (simple decay)</td>
<td>3-D transport of solute (simple decay) [SZ BTC 7]  &lt;br&gt; 1-D transport only the mass created by ingrowth from $^{230}$Th decay</td>
<td>Dose from 3-D and 1-Df</td>
</tr>
<tr>
<td>$^{79}$Se</td>
<td>Transport solute</td>
<td>Transport solute</td>
<td>3-D transport of nonsorbing solute [SZ BTC 11]</td>
<td>Dose from 3-Df</td>
</tr>
<tr>
<td>$^{126}$Sn</td>
<td>Transport reversible colloid and solute</td>
<td>Transport reversible colloid and solute</td>
<td>3-D transport of tin reversible colloid and solute [SZ BTC 12]</td>
<td>Dose from 3-D</td>
</tr>
<tr>
<td>$^{90}$Sr</td>
<td>Transport solute</td>
<td>Transport solute</td>
<td>3-D transport of strontium solute [SZ BTC 8]</td>
<td>Dose from 3-Dg</td>
</tr>
<tr>
<td>$^{99}$Tc</td>
<td>Transport solute</td>
<td>Transport solute</td>
<td>3-D transport of nonsorbing solute [SZ BTC 1]</td>
<td>Dose from 3-D</td>
</tr>
<tr>
<td>$^{229}$Th</td>
<td>Transport reversible colloid and solute (simple decay)</td>
<td>Transport reversible colloid and solute (simple decay)</td>
<td>3-D transport of reversible colloid and solute (simple decay) [SZ BTC 2]  &lt;br&gt; 1-D transport only the mass created by ingrowth from $^{229}$U decay</td>
<td>Dose from 3-D and 1-Df</td>
</tr>
<tr>
<td>$^{230}$Th</td>
<td>Transport reversible colloid and solute (decay to $^{226}$Ra)</td>
<td>Transport reversible colloid and solute (decay to $^{226}$Ra)</td>
<td>1-D transport of reversible colloid and solute (decay to $^{226}$Ra) [SZ BTC 2]</td>
<td>Dose from 1-Df</td>
</tr>
<tr>
<td>$^{232}$Th</td>
<td>Transport reversible colloid and solute (decay to $^{228}$Ra)</td>
<td>Transport reversible colloid and solute (simple decay)</td>
<td>3-D transport of reversible colloid and solute (decay to $^{228}$Ra) [SZ BTC 2]  &lt;br&gt; 1-D transport only the mass created by ingrowth from $^{232}$U decay</td>
<td>Dose from 3-D and 1-Df</td>
</tr>
<tr>
<td>$^{232}$U</td>
<td>Transport reversible colloid and solute</td>
<td>Transport solute</td>
<td>3-D transport of $^{234}$U solute [SZ BTC 9]</td>
<td>Dose from 3-D</td>
</tr>
</tbody>
</table>
Table 6.3.7-6[a]. Disposition of Radionuclides for Groundwater Release Modeling Cases: Nominal, Igneous Intrusion, and Seismic (Continued)

<table>
<thead>
<tr>
<th>Radionuclide (Table 6.3.7-2)</th>
<th>Disposition in Waste Form, EBS, and UZ TSPA-LA Model Components (Section 6.3.7)</th>
<th>Disposition in 3-D UZ FEHM Submodel&lt;sup&gt;a&lt;/sup&gt; (Section 6.3.9)</th>
<th>Disposition in SZ Submodels &lt;sup&gt;b&lt;/sup&gt; (3-D SZ_Convolute and 1-D Pipe)&lt;sup&gt;b&lt;/sup&gt; (Section 6.3.10 and 6.3.10[a])</th>
<th>Disposition in Biosphere (Section 6.3.11)</th>
</tr>
</thead>
<tbody>
<tr>
<td>233U Transport reversible colloid and solute (decay to 229Th)</td>
<td>Transport solute (decay to 229Th)</td>
<td>1-D transport of solute (decay to thorium) [SZ BTC 9]</td>
<td>Dose from 1-D</td>
<td></td>
</tr>
<tr>
<td>234U Transport reversible colloid and solute (decay to 230Th)</td>
<td>Transport solute (decay to 230Th)</td>
<td>3-D transport of 234U solute, [SZ BTC 9], boosted&lt;sup&gt;c&lt;/sup&gt; by 238Pu&lt;sub&gt;irs&lt;/sub&gt;, 238Pu&lt;sub&gt;ur&lt;/sub&gt;, and 238Pu&lt;sub&gt;revisol&lt;/sub&gt;</td>
<td>Dose from 3-D</td>
<td></td>
</tr>
<tr>
<td>235U Transport reversible colloid and solute (decay to 231Pa)</td>
<td>Transport solute (decay to 231Pa)</td>
<td>1-D transport of solute (decay to 231Pa) [SZ BTC 9]</td>
<td>Dose from 1-D&lt;sup&gt;f&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>236U Transport reversible colloid and solute (decay to 232Th)</td>
<td>Transport solute (decay to 232Th)</td>
<td>3-D transport of 236U solute [SZ BTC 9], boosted&lt;sup&gt;d&lt;/sup&gt; by 240Pu&lt;sub&gt;irs&lt;/sub&gt;, 240Pu&lt;sub&gt;ur&lt;/sub&gt;, and 240Pu&lt;sub&gt;revisol&lt;/sub&gt;</td>
<td>Dose from 3-D</td>
<td></td>
</tr>
<tr>
<td>238U Transport reversible colloid and solute (decay to 234U)</td>
<td>Transport solute (decay to 234U)</td>
<td>3-D transport of 238U solute [SZ BTC 9], boosted&lt;sup&gt;g&lt;/sup&gt; by 242Pu&lt;sub&gt;irs&lt;/sub&gt;, 242Pu&lt;sub&gt;ur&lt;/sub&gt;, and 242Pu&lt;sub&gt;revisol&lt;/sub&gt;</td>
<td>Dose from 3-D</td>
<td></td>
</tr>
</tbody>
</table>

**NOTE:**

<sup>a</sup> Plutonium and americium isotopes are transported irreversibly on two different colloid types in the EBS: iron oxyhydroxide colloids (e.g., see 239Pu<sub>FeO</sub> in the above table) and waste form colloids (e.g., see 239Pu<sub>emb</sub> in the above table). However, at the EBS-UZ interface, the plutonium or americium mass associated with these two types of colloids is combined (effectively losing or ignoring the mineral specificity) and then resplit into slow-transport and fast-transport irreversible colloids in the natural system (e.g., see 239Pu<sub>irs</sub> and 239Pu<sub>ur</sub> in the above table). Thus, the specific radionuclides in GoldSim, designated “Ic” and “If”, are used differently in the EBS versus the natural system—in the EBS “Ic” stands for plutonium and americium mass transported in “embedded” colloids (i.e., the plutonium and americium mass is embedded in the mineral matrix of these colloid particles), and “If” stands for plutonium and americium mass sorbed irreversibly onto iron oxyhydroxide colloids, whereas in the UZ (Section 6.3.9) and SZ (Section 6.3.10), “Ic” stands for plutonium and americium mass transported irreversibly on slow colloids, and “If” stands for plutonium or americium mass transported irreversibly on fast colloids.

<sup>b</sup> Saturated Zone Breakthrough Curve and the associated number refers to the “Radionuclide Group Number” listed in the first column of Table 6.3.10-1 (Section 6.3.10).

<sup>c</sup> Boosting of a daughter (e.g., 238Pu) means that the injected mass of the daughter over any timestep at the UZ-SZ interface is increased by the maximum decay (over the remaining simulation time) of the designated parent (e.g., 242Am).

<sup>d</sup> 245Cm and 241Pu were recommended for inclusion in the TSPA-LA in *Radionuclide Screening* (SNL 2007 [DIRS 177424], Section 6.6.2 and Table 6-9) only to ensure that the effect of their decay on the inventories of 241Am and 237Np are included in the model. They are not recommended for transport or dose consequences.

<sup>e</sup> Though 210Pb is not tracked, it is assumed to be in secular equilibrium with 226Ra; that is, the biosphere dose conversion (BDCF) used for 226Ra is the summation of the BDCFs provided for 226Ra and 210Pb.

<sup>f</sup> Doses only calculated for 1,000,000-year simulations (SNL 2007 [DIRS 177424], Table 6-9).

<sup>g</sup> Doses only calculated for 10,000-year simulations (SNL 2007 [DIRS 177424], Table 6-9).

SZ BTC = Saturated Zone Breakthrough Curve.
<table>
<thead>
<tr>
<th>TSPA-LA Parameter Name</th>
<th>Model Abstraction Symbol</th>
<th>Description</th>
<th>Units</th>
<th>Distribution Type</th>
<th>Distribution Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conc.Col.U.Sampled_a</td>
<td>$m_{\text{coll,uranophane, sampled}}$</td>
<td>Expected mass of uranophane colloids per unit volume or mass of water.</td>
<td>mg/L</td>
<td>Cumulative Distribution Function</td>
<td>Prob Level</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.75</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.90</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.98</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Conc.Col.U.Min</td>
<td>$m_{\text{coll,uranophane, min}}$</td>
<td>Lowest observed or expected mass of uranophane colloids per unit volume or mass of water.</td>
<td>mg/L</td>
<td>Single Value</td>
<td>$1 \times 10^{-6}$</td>
</tr>
<tr>
<td>U.PH.Lo</td>
<td>None</td>
<td>Lower limit of pH range for U colloid stability data.</td>
<td>None</td>
<td>Single Value</td>
<td>4</td>
</tr>
<tr>
<td>U.PH.Hi</td>
<td>None</td>
<td>Upper limit of pH range for U colloid stability data.</td>
<td>None</td>
<td>Single Value</td>
<td>9</td>
</tr>
<tr>
<td>Coeff.pH.Sq.U</td>
<td>None</td>
<td>Coefficient of pH squared term for fit of ionic strength threshold for U colloid stability.</td>
<td>None</td>
<td>Single Value</td>
<td>-0.008</td>
</tr>
<tr>
<td>Coeff.pH.U</td>
<td>None</td>
<td>Coefficient of pH term for fit of ionic strength threshold for U colloid stability.</td>
<td>None</td>
<td>Single Value</td>
<td>0.14</td>
</tr>
<tr>
<td>Coeff.inter.U</td>
<td>None</td>
<td>Coefficient of intercept term for fit of ionic strength threshold for U colloid stability.</td>
<td>None</td>
<td>Single Value</td>
<td>0.4</td>
</tr>
<tr>
<td>Kd.Pu_Rev.U.Col.a</td>
<td>$K_{d_{\text{Pu,uranophane}}}$</td>
<td>Distribution coefficient for reversible sorption of plutonium onto uranophane colloids.</td>
<td>mL/g</td>
<td>Log Uniform</td>
<td>$5 \times 10^{5}$ to $1 \times 10^{4}$</td>
</tr>
<tr>
<td>Kd.Am_Rev.U.Col.a</td>
<td>$K_{d_{\text{Am,uranophane}}}$</td>
<td>Distribution coefficient for reversible sorption of americium onto uranophane colloids.</td>
<td>mL/g</td>
<td>Log Uniform</td>
<td>$5 \times 10^{5}$ to $1 \times 10^{4}$</td>
</tr>
<tr>
<td>Kd.Th_Rev.U.Col.a</td>
<td>$K_{d_{\text{Th,uranophane}}}$</td>
<td>Distribution coefficient for reversible sorption of thorium onto uranophane colloids.</td>
<td>mL/g</td>
<td>Log Uniform</td>
<td>$5 \times 10^{5}$ to $1 \times 10^{4}$</td>
</tr>
</tbody>
</table>
Table 6.3.7-64[a]. Parameters for TSPA-LA SNF Waste Form Reversible Colloid Abstraction (Continued)

<table>
<thead>
<tr>
<th>TSPA-LA Parameter Name</th>
<th>Model Abstraction Symbol</th>
<th>Description</th>
<th>Units</th>
<th>Distribution Type</th>
<th>Distribution Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kd_Pa_Rev_U_Col_a</td>
<td>$K_d,Pa_{coll,uranophane}$</td>
<td>Distribution coefficient for reversible sorption of Pa onto uranophane colloids.</td>
<td>mL/g</td>
<td>Log Uniform</td>
<td>$5 \times 10^0$ to $1 \times 10^4$</td>
</tr>
<tr>
<td>Kd-Cs_Rev_U_Col_a</td>
<td>$K_d,Cs_{coll,uranophane}$</td>
<td>Distribution coefficient for reversible sorption of cesium onto uranophane colloids.</td>
<td>mL/g</td>
<td>Log Uniform</td>
<td>$1 \times 10^1$ to $1 \times 10^3$</td>
</tr>
<tr>
<td>Kd_Np_Rev_U_Col_a</td>
<td>$K_d,Np_{coll,uranophane}$</td>
<td>Distribution coefficient for reversible sorption of neptunium onto uranophane colloids.</td>
<td>mL/g</td>
<td>Log Uniform</td>
<td>$1 \times 10^1$ to $5 \times 10^2$</td>
</tr>
<tr>
<td>Kd_Ra_Rev_U_Col_a</td>
<td>$K_d,Ra_{coll,uranophane}$</td>
<td>Distribution coefficient for reversible sorption of radium onto uranophane colloids.</td>
<td>mL/g</td>
<td>Log Uniform</td>
<td>$1 \times 10^1$ to $1 \times 10^3$</td>
</tr>
<tr>
<td>Kd_Sn_Rev_U_Col_a</td>
<td>$K_d,Sn_{coll,uranophane}$</td>
<td>Distribution coefficient for reversible sorption of tin onto uranophane colloids.</td>
<td>mL/g</td>
<td>Log Uniform</td>
<td>$1 \times 10^0$ to $1 \times 10^2$</td>
</tr>
<tr>
<td>Specific_SA_U_Col</td>
<td>$S_A, uranophane, coll$</td>
<td>Specific surface area for uranophane.</td>
<td>m$^2$/g</td>
<td>Single Value</td>
<td>30</td>
</tr>
<tr>
<td>U_Site_Density</td>
<td>$N_S, uranophane, coll$</td>
<td>Site density for uranophane particle colloid.</td>
<td>Sites/ nm$^2$</td>
<td>Single Value</td>
<td>2</td>
</tr>
</tbody>
</table>

Source: DTN: MO0701PACSNFCP.000_R1 [DIRS 180439], File: DTN_SNF_REV03.doc.

NOTE: Condition report 11424 describes the errata in the source documents.
6.3.8[a] Engineered Barrier System Transport

Table 6.3.8-4 of the parent document was updated (Table 6.3.8-4[a]) to reflect the update to the TSPA-LA Model for the adsorption isotherm parameter \( k \) and parameter \( s \) for corrosion products incorrectly implemented (Appendix P[a], Table P-6[a], Item 7).
Table 6.3.8-4[a]. Sampled Model Inputs Used in the EBS Radionuclide Transport Abstraction

<table>
<thead>
<tr>
<th>Input Name</th>
<th>Input Description</th>
<th>Range</th>
<th>Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Invert_Diff_Coeff_Uncert_a</td>
<td>Invert diffusion coefficient uncertainty</td>
<td>Range: $10^{0.33\sigma}$ (dimensionless) Mean: $\mu = 0.033$ Std. Dev. $\sigma = 0.218$</td>
<td>Truncated Normal</td>
</tr>
<tr>
<td>SS_Corrosion_Rate_a</td>
<td>Stainless steel corrosion rate</td>
<td>Mean = 0.267 $\mu$m/yr Std. Dev. = 0.209 $\mu$m/yr</td>
<td>Truncated Lognormal</td>
</tr>
<tr>
<td>CS_Corrosion_Rate_a</td>
<td>Carbon steel corrosion rate</td>
<td>Mean = 0.267 $\mu$m/yr Std. Dev. = 0.209 $\mu$m/yr</td>
<td>Truncated Lognormal</td>
</tr>
<tr>
<td>DS_Flux_Uncertainty_a</td>
<td>Drip shield flux-splitting uncertainty factor</td>
<td>Mean = 0.267 $\mu$m/yr Std. Dev. = 0.209 $\mu$m/yr</td>
<td>Truncated Lognormal</td>
</tr>
<tr>
<td>WP_Flux_Uncertainty_a</td>
<td>Waste package flux-splitting uncertainty factor</td>
<td>Mean = 0.267 $\mu$m/yr Std. Dev. = 0.209 $\mu$m/yr</td>
<td>Truncated Lognormal</td>
</tr>
<tr>
<td>Diameter_Colloid_a</td>
<td>Diameter of colloid particle</td>
<td>50 – 300 nm</td>
<td>Uniform</td>
</tr>
<tr>
<td>Goethite_SA_a</td>
<td>Specific surface area of goethite (FeOOH)</td>
<td>Mean = 51.42 $m^2/g$ Std. Dev. = 30.09 $m^2/g$</td>
<td>Lognormal (Truncated)</td>
</tr>
<tr>
<td>HFO_SA_a</td>
<td>Specific surface area of HFO</td>
<td>Mean = 275.6 $m^2/g$ Std. Dev. = 113.4 $m^2/g$</td>
<td>Lognormal (Truncated)</td>
</tr>
<tr>
<td>NiO_SA_a</td>
<td>Specific surface area of NiO</td>
<td>1 – 30 $m^2/g$</td>
<td>Uniform</td>
</tr>
<tr>
<td>Cr2O3_SA_a</td>
<td>Specific surface area of Cr2O3</td>
<td>1 – 20 $m^2/g$</td>
<td>Uniform</td>
</tr>
<tr>
<td>Relative_Abundance_Goethite_a</td>
<td>Mass fraction of iron oxides (goethite and HFO) that is goethite</td>
<td>0.45 – 0.80 (fraction)</td>
<td>Uniform</td>
</tr>
<tr>
<td>FHH_Isotherm_k_CP_a_5003[^a]</td>
<td>FHH adsorption isotherm parameter k for corrosion products</td>
<td>1.030 – 1.326 (dimensionless)</td>
<td>Uniform</td>
</tr>
<tr>
<td>FHH_Isotherm_s_CP_a_5003[^a]</td>
<td>FHH adsorption isotherm parameter s for corrosion products</td>
<td>1.493 – 1.799 (dimensionless)</td>
<td>Uniform</td>
</tr>
<tr>
<td>CSNF_Rind_SA_a</td>
<td>Specific surface area of CSNF rind</td>
<td>0.5 – 60 $m^2/g$</td>
<td>Uniform</td>
</tr>
<tr>
<td>Density_CSNF_Rind_a</td>
<td>Density of CSNF rind</td>
<td>5,600 – 11,500 $kg/m^3$</td>
<td>Uniform</td>
</tr>
<tr>
<td>Porosity_Rind_CSNF_a</td>
<td>Porosity of CSNF rind</td>
<td>0.05 – 0.3 (fraction)</td>
<td>Uniform</td>
</tr>
<tr>
<td>FHH_Isotherm_k_CSNF_Rind_a</td>
<td>FHH adsorption isotherm parameter k for CSNF rind</td>
<td>1.606 – 8.215 (dimensionless)</td>
<td>Uniform</td>
</tr>
<tr>
<td>FHH_Isotherm_s_CSNF_Rind_a</td>
<td>FHH adsorption isotherm parameter s for CSNF rind</td>
<td>1.656 – 3.038 (dimensionless)</td>
<td>Uniform</td>
</tr>
<tr>
<td>HLWG_Rind_SA_a</td>
<td>Specific surface area of high-level radioactive water glass (HLWG) rind</td>
<td>10 – 38 $m^2/g$</td>
<td>Uniform</td>
</tr>
<tr>
<td>Diameter_Colloid_a</td>
<td>Colloid particle diameter</td>
<td>50 – 300 nm</td>
<td>Uniform</td>
</tr>
<tr>
<td>Gamma_AFМ_a</td>
<td>Active fracture model gamma parameter</td>
<td>DTN: LA0701PANS02BR.003_R2 [DIRS 180497], Readme File</td>
<td>Uniform</td>
</tr>
</tbody>
</table>
Table 6.3.8-4[a]. Sampled Model Inputs Used in the EBS Radionuclide Transport Abstraction (Continued)

<table>
<thead>
<tr>
<th>Input Name</th>
<th>Input Description</th>
<th>Range</th>
<th>Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>EBS_UZ_Flux_Sat_PS1</td>
<td>Unsaturated zone fracture saturation DTN: LA0701PANS02BR.003_R2 [DIRS 180497].</td>
<td>Average values for the five percolation subregions based on the average of repository nodes in each percolation subregion.</td>
<td>2-D Table; see Table 6.3.8-5</td>
</tr>
<tr>
<td>EBS_UZ_Flux_Sat_PS2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EBS_UZ_Flux_Sat_PS3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EBS_UZ_Flux_Sat_PS4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EBS_UZ_Flux_Sat_PS5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pH_Cell2_Regression_Error_a</td>
<td>Error term added to the surface complexation based pH calculation in the corrosion products domain.</td>
<td>Mean: $\mu = 0$; Std. Dev. $\sigma = 0.32$ Truncated at $\pm 2$ Std. Dev.</td>
<td>Truncated Normal</td>
</tr>
<tr>
<td>Diff_Path_Length_Invert_Top_a</td>
<td>Diffusive path length from waste package outer corrosion barrier (OCB) to mid-point of invert.</td>
<td>0.30 – 1.24 m</td>
<td>Uniform</td>
</tr>
</tbody>
</table>

Sources: Modified from DTN: SN0703PAEBSRTA.001_R3 [DIRS 183217], Files: SN0703PAEBSRTA.001_RTA Input Tables.doc and Corrosion Products Composite Isotherm 7-19-2007.xls.

NOTES: a Condition Report 11755 documents this error which is being addressed in this Addendum.
6.3.9[a] Unsaturated Zone Transport

The analyses documented in this addendum include a change to Table 6.3.9-1[a] that reflects the radionuclide half-lives documented in the parent document (Appendix P[a], Table P-6[a], Item 2). In addition input errors discovered during the checking of the TSPA Input Database have been corrected and are documented in Table P-6[a], Item 10 and Item 11. Section 6.3.9.4[a] contains an expanded discussion of the consistency of assumptions for UZ Transport Properties. The following text details the amendments to the UZ Transport Submodel implementation in support of the analyses documented in this addendum.

6.3.9.1[a] Conceptual Model

No change.

6.3.9.2[a] TSPA-LA Model Abstraction

To ensure consistency among the EBS Transport Submodel, UZ Transport Submodel, and SZ Transport Submodel, the radionuclide half-lives used in the UZ Transport Submodel were changed to the values listed in Table 6.3.9-1[a] (DTN: MO0702PASTREAM.001_R0 [DIRS 179925]) for the analyses presented in this addendum.

6.3.9.3[a] TSPA LA Model Implementation

No change.

6.3.9.4[a] Model Component Consistency and Conservatism in Assumptions and Parameters

An expanded discussion of the UZ Transport Properties consistency of assumptions is included in Section 6.3.9.4.1[a]. This discussion is a more detailed documentation of the consistency in UZ Transport Properties and is provided as a replacement to the material included in Section 6.3.9.4.1 of the parent document. The remainder of Section 6.3.9.4 included in the parent document remains unchanged.

6.3.9.4.1[a] Consistency of Assumptions

UZ Transport Properties—In the Unsaturated Zone Transport Submodel, the calibrated values of parameters used to develop the pre-generated flow fields do not explicitly match the values used to generate the matrix-diffusion parameters. In general, the parameters used to describe flow and transport are the same (SNL 2008 [DIRS 184748], Sections 6.5.5.4[a], 6.5.7, and A.4[a]; SNL 2007 [DIRS 184614], Section 6.1.5; and SNL 2007 [DIRS 179545]). An exception is the range of values of the active fracture model parameter $\gamma$ as discussed in Particle Tracking Model and Abstraction of Transport Processes (SNL 2008 [DIRS 184748], Section 6.5.6 [a]).

The matrix-diffusion process implemented in the Unsaturated Zone Transport Submodel is sensitive to various physical parameters that are also used to define the UZ flow fields. Because the matrix-diffusion process may be very sensitive to these parameters, it is important to propagate the uncertainties in parameter values into the Unsaturated Zone Transport Submodel.
There are several UZ flow-related parameters used by the radionuclide transport model. Parameters used directly are: matrix porosity, fracture porosity, fracture spacing (the inverse of fracture frequency), and the active fracture model parameter $\gamma$. These parameters are deterministic in the UZ Flow Model.

Several matrix hydrologic parameters are also used indirectly to develop mean values of tortuosity (SNL 2008 [DIRS 184748], Section A.2[a]) using a correlation between matrix effective permeability and water content for tortuosity (matrix diffusion) (Equation 6.3.9-1). The matrix parameters used to determine tortuosity are: porosity, residual saturation, capillary strength (van Genuchten $\alpha$), pore size distribution index (van Genuchten $m$), and permeability (SNL 2008 [DIRS 184748], Section A.2[a]). Deterministic values are used to compute mean tortuosity values for each of three rock categories; tortuosity is then sampled based on the uncertainty in the tortuosity correlation associated with differences between diffusion coefficient values predicted by Equation 6.3.9-1 and measured values (SNL 2008 [DIRS 184748], Section A.4[a]).

**Effect on the TSPA Model**—A study presented in *UZ Flow Models and Submodels* (BSC 2004 [DIRS 169861], Section 6.8.1) indicates that the Site-Scale UZ Flow Model is relatively insensitive to changes in the value of the active fracture model parameter $\gamma$. In the steady-state site-scale UZ Flow Model, the active fracture model parameter $\gamma$ influences the partitioning of water flow between the fractures and rock matrix. The conclusion of the study noted that for the flow model, changing the values of active fracture model parameter $\gamma$ will have only a small effect on matrix liquid saturations, water potentials, and average percolation fluxes. This may also indicate that $\gamma$ values, estimated based on flow calibrations, may not be well constrained, and the application of a greater uncertainty for transport calculations is valid. Note, the *UZ Flow Models and Submodels* referenced above is a historical document that was revised to incorporate new infiltration data (SNL 2007 [DIRS 184614]). Several sensitivity analyses presented in the historical version, which are still valid despite changes in the infiltration data, were not repeated or discussed in the current version but are needed for this discussion.

The aperture values used in the UZ Transport Model are generated from fracture porosity and fracture frequency (the inverse of fracture spacing) values. In general, the large permeability contrast between the fractures and rock matrix (SNL 2007 [DIRS 184614], Appendix B) indicates that the rock matrix will not contribute significantly to the flow process (minimizing the influence of fracture spacing), and matrix diffusion will be the dominant process controlling mass retardation in the rock matrix. In addition, fracture porosities are important in defining the transient matrix-diffusion process in the UZ Transport Model. However, as storage terms in the site-scale UZ Flow Model, they do not influence results of the steady-state model. It should also be noted that fracture permeabilities and van Genuchten $\alpha$ parameters are related to fracture apertures (BSC 2004 [DIRS 170038], Section 6.1.2). A sensitivity study on flow model parameters showed relatively small differences between base-case flow fields and flow fields generated by changing fracture permeabilities and van Genuchten $\alpha$ parameters (BSC 2005 [DIRS 174116], Section 6.3). Studies presented in *Particle Tracking Model and Abstraction of Transport Processes* (SNL 2008 [DIRS 184748], Sections 6.6.3 and 6.6.4) also showed that transport in the UZ is generally less sensitive to changes in flow parameters than to changes in the transport properties. The analyses showed that the transport results were insensitive to the van Genuchten $\alpha$ parameter. Transport results showed greater sensitivity to changes in fracture
permeability compared to that of the van Genuchten $\alpha$ parameter, but as noted, the changes were relatively small.

The mean values for tortuosity used in the UZ Transport Submodel are based on the deterministic values of porosity, residual saturation, capillary strength (van Genuchten $\alpha$), pore size distribution index (van Genuchten $m$), and permeability used in the 10th percentile infiltration scenario for the UZ Site-Scale Flow Model present-day, monsoon, glacial-transition, and post-10,000-year simulations. The 10th percentile infiltration scenario is the most commonly sampled infiltration scenario (62 percent of the time). Additionally, it can be shown that tortuosity values generated using deterministic parameters from the other infiltration scenarios differ only slightly from the values used in the TSPA-LA Model. The uncertainty in tortuosity values considered in the transport calculations is the uncertainty in the correlation between the tortuosity and fracture permeability and porosity and, therefore, is only pertinent to the transport calculations.

6.3.9.5[a] Alternative Conceptual Model(s) for Unsaturated Zone Transport

No change.
INTENTIONALLY LEFT BLANK
Table 6.3.9-1[a]. Radionuclide Half-Life and Daughter Products Used in the TSPA-LA Addendum

<table>
<thead>
<tr>
<th>No.</th>
<th>Species</th>
<th>Half Life (years)</th>
<th>Daughter Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$^{14}$C</td>
<td>$5.72 \times 10^3$</td>
<td>NA</td>
</tr>
<tr>
<td>2</td>
<td>$^{135}$Cs (rev)</td>
<td>$2.30 \times 10^6$</td>
<td>NA</td>
</tr>
<tr>
<td>3</td>
<td>$^{137}$Cs (rev)</td>
<td>$3.01 \times 10^1$</td>
<td>NA</td>
</tr>
<tr>
<td>4</td>
<td>$^{129}$I</td>
<td>$1.57 \times 10^7$</td>
<td>NA</td>
</tr>
<tr>
<td>5</td>
<td>$^{90}$Sr</td>
<td>$2.88 \times 10^1$</td>
<td>NA</td>
</tr>
<tr>
<td>6</td>
<td>$^{99}$Tc</td>
<td>$2.13 \times 10^5$</td>
<td>NA</td>
</tr>
<tr>
<td>7</td>
<td>$^{243}$Am (rev)</td>
<td>$7.37 \times 10^3$</td>
<td>10</td>
</tr>
<tr>
<td>8</td>
<td>$^{243}$Am$^{lc}$</td>
<td>$7.37 \times 10^3$</td>
<td>11</td>
</tr>
<tr>
<td>9</td>
<td>$^{243}$Am$^{lf}$</td>
<td>$7.37 \times 10^3$</td>
<td>12</td>
</tr>
<tr>
<td>10</td>
<td>$^{239}$Pu (rev)</td>
<td>$2.41 \times 10^4$</td>
<td>13</td>
</tr>
<tr>
<td>11</td>
<td>$^{239}$Pu$^{lc}$</td>
<td>$2.41 \times 10^4$</td>
<td>13</td>
</tr>
<tr>
<td>12</td>
<td>$^{239}$Pu$^{lf}$</td>
<td>$2.41 \times 10^4$</td>
<td>13</td>
</tr>
<tr>
<td>13</td>
<td>$^{235}$U</td>
<td>$7.04 \times 10^5$</td>
<td>14</td>
</tr>
<tr>
<td>14</td>
<td>$^{231}$Pa (rev)</td>
<td>$3.28 \times 10^4$</td>
<td>NA</td>
</tr>
<tr>
<td>15</td>
<td>$^{241}$Am (rev)</td>
<td>$4.33 \times 10^2$</td>
<td>18</td>
</tr>
<tr>
<td>16</td>
<td>$^{241}$Am$^{lc}$</td>
<td>$4.33 \times 10^2$</td>
<td>18</td>
</tr>
<tr>
<td>17</td>
<td>$^{241}$Am$^{lf}$</td>
<td>$4.33 \times 10^2$</td>
<td>18</td>
</tr>
<tr>
<td>18</td>
<td>$^{237}$Np</td>
<td>$2.14 \times 10^6$</td>
<td>19</td>
</tr>
<tr>
<td>19</td>
<td>$^{233}$U</td>
<td>$1.59 \times 10^5$</td>
<td>20</td>
</tr>
<tr>
<td>20</td>
<td>$^{229}$Th (rev)</td>
<td>$7.30 \times 10^3$</td>
<td>NA</td>
</tr>
<tr>
<td>21</td>
<td>$^{240}$Pu (rev)</td>
<td>$6.56 \times 10^3$</td>
<td>24</td>
</tr>
<tr>
<td>22</td>
<td>$^{240}$Pu$^{lc}$</td>
<td>$6.56 \times 10^3$</td>
<td>24</td>
</tr>
<tr>
<td>23</td>
<td>$^{240}$Pu$^{lf}$</td>
<td>$6.56 \times 10^3$</td>
<td>24</td>
</tr>
<tr>
<td>24</td>
<td>$^{236}$U</td>
<td>$2.34 \times 10^7$</td>
<td>25</td>
</tr>
<tr>
<td>25</td>
<td>$^{232}$Th (rev)</td>
<td>$1.40 \times 10^10$</td>
<td>NA</td>
</tr>
<tr>
<td>26</td>
<td>$^{232}$U</td>
<td>$6.98 \times 10^1$</td>
<td>NA</td>
</tr>
<tr>
<td>27</td>
<td>$^{242}$Pu (rev)</td>
<td>$3.75 \times 10^5$</td>
<td>33</td>
</tr>
<tr>
<td>28</td>
<td>$^{242}$Pu$^{lc}$</td>
<td>$3.75 \times 10^5$</td>
<td>33</td>
</tr>
<tr>
<td>29</td>
<td>$^{242}$Pu$^{lf}$</td>
<td>$3.75 \times 10^5$</td>
<td>33</td>
</tr>
<tr>
<td>30</td>
<td>$^{238}$Pu (rev)</td>
<td>$8.77 \times 10^1$</td>
<td>34</td>
</tr>
<tr>
<td>31</td>
<td>$^{238}$Pu$^{lc}$</td>
<td>$8.77 \times 10^1$</td>
<td>34</td>
</tr>
<tr>
<td>32</td>
<td>$^{238}$Pu$^{lf}$</td>
<td>$8.77 \times 10^1$</td>
<td>34</td>
</tr>
<tr>
<td>33</td>
<td>$^{238}$U</td>
<td>$4.47 \times 10^5$</td>
<td>34</td>
</tr>
<tr>
<td>34</td>
<td>$^{234}$U</td>
<td>$2.46 \times 10^5$</td>
<td>35</td>
</tr>
<tr>
<td>35</td>
<td>$^{230}$Th (rev)</td>
<td>$7.54 \times 10^4$</td>
<td>36</td>
</tr>
<tr>
<td>36</td>
<td>$^{226}$Ra</td>
<td>$1.60 \times 10^3$</td>
<td>NA</td>
</tr>
<tr>
<td>37</td>
<td>$^{36}$Cl</td>
<td>$3.01 \times 10^5$</td>
<td>NA</td>
</tr>
<tr>
<td>38</td>
<td>$^{78}$Se</td>
<td>$2.90 \times 10^5$</td>
<td>NA</td>
</tr>
<tr>
<td>39</td>
<td>$^{126}$Sn (rev)</td>
<td>$2.30 \times 10^5$</td>
<td>NA</td>
</tr>
</tbody>
</table>

Source: DTN: MO0702PASTREAM.001_R0 [DIRS 179925], File: DTN-Inventory-Rev00.xls.
NOTES: rev = reversible colloids.
Daughter Index lists the radionuclide species number of the daughters produced for decay-chain species.
* Denotes the half-life value used in the analyses documented in the parent document.
6.3.10[a] Saturated Zone Flow and Transport Model Component

The analyses documented in this addendum include changes necessary to reflect the most recent addendum to *Saturated Zone Flow and Transport Model Abstraction* (SNL 2008 [DIRS 183750]). The discussions below supplement the material presented in Section 6.3.10 of the parent document, noting differences between the 3-D and 1-D SZ Flow and Transport Abstractions used in the analyses documented in this addendum.

6.3.10.1[a] Conceptual Model

No change.

6.3.10.2[a] TSPA-LA Model Abstraction

As documented in the parent document, two abstractions of the SZ Flow and Transport Model Component were implemented in the TSPA-LA Model:  (1) the 3-D SZ Flow and Transport Abstraction Model, which uses a convolution integral technique to combine radionuclide breakthrough curves with time-varying radionuclide sources from the UZ to quantify radionuclide transport to the accessible environment, and (2) the 1-D SZ Flow and Transport Abstraction implemented directly in the TSPA-LA Model to calculate radioactive decay, ingrowth, and transport for specified radionuclide chains. These analyses incorporate amendments to both the 3-D and 1-D SZ Transport Model Abstractions, as documented in *Saturated Zone Flow and Transport Model Abstraction* (SNL 2008 [DIRS 183750] and DTN: SN0710PASZFTMA.003_R0 [DIRS 183485]). The following sections detail the amendments to the SZ Transport Submodel abstraction and implementation in support of the analyses documented in this addendum.

3-D SZ Flow and Transport Abstraction—The three-dimensional SZ flow and transport process modeling, described in *Saturated Zone Site-Scale Flow Model* (SNL 2007 [DIRS 177391]) and *Site-Scale Saturated Zone Transport* (SNL 2008 [DIRS 184806]), forms the technical basis for the 3-D SZ Flow and Transport Abstraction, as documented in the parent document for the TSPA-LA Model. The analyses documented within this addendum utilize the same abstraction documented in the parent document (SNL 2008 [DIRS 183750], Section 6.3.1[a]). The 3-D SZ Flow and Transport Abstraction used for the analyses presented in this addendum differs from the parent document (DTNs: SN0702PASZFTMA.002_R1 [DIRS 183471], File: Test_SZ_Sampled_Vectors_latest.txt, and SN0702PASZFTMA.001 [DIRS 179504], File: output_to_TSPA-dir.zip) only in the updated half-life values for $^{79}\text{Se}$ and $^{126}\text{Sn}$, reflecting a revision to the source data for the radionuclide half-lives (DTN: MO0702PASTREAM.001_R0 [DIRS 179925], File: DTN-Inventory-Rev00.xls).

1-D SZ Flow and Transport Abstraction—Because the ingrowth of radionuclides is not explicitly included in the 3-D SZ Flow and Transport Abstraction, a 1-D SZ Flow and Transport Abstraction is used to account for the decay and ingrowth of radionuclide daughter products for the four decay chains shown on Figure 6.3.10-8[a]. The updated 1-D SZ Flow and Transport Abstraction (DTN: SN0710PASZFTMA.003_R0 [DIRS 183485], File: Compliance_Sampling_with_LDISP_Changes_Truncated.txt) includes the same uncertain input parameters as the 3-D SZ Flow and Transport Abstraction. With one exception, these input parameters are...
identical to those documented in Table 6.3.10-2 of the parent document. However, the longitudinal dispersivity that is used in the 1-D SZ Flow and Transport Model for the analyses documented in the parent document has an unbounded lognormal distribution that defines the epistemic uncertainty in longitudinal dispersivity (Table 6.3.10-2). The sampled value is further adjusted by increasing it by one order of magnitude (SNL 2008 [DIRS 183750], Section 6.5.1.2[a]). As documented in Section P15 of the parent document, the values calculated for the longitudinal dispersivity could become larger than are physically possible. The analyses documented in this addendum include an amended distribution for longitudinal dispersivity values used in the 1-D SZ Flow and Transport Abstraction (DTN: SN0710PASZFTMA.003_R0 [DIRS 183485], File: Compliance_Sampling_with_LDISP_Changes_Truncated.txt). The normal distribution for the logarithm of the longitudinal dispersivity ($\alpha_L$), implemented in the 1-D SZ Flow and Transport Model for the analyses documented in this addendum, was truncated at the upper end at two standard deviations from the mean, and the sampled value was used directly without further adjustment (DTN: SN0710PASZFTMA.003_R0 [DIRS 183485], File: Readme.txt).

6.3.10.3[a] TSPA-LA Model Implementation

For the analyses documented in this addendum, the 1-D SZ Flow and Transport Abstraction is used to account for the ingrowth of the second-, third-, or fourth-generation daughters: $^{235}$U, $^{231}$Pa, $^{227}$Ac, $^{233}$U, $^{229}$Th, $^{232}$Th, $^{228}$Ra, $^{230}$Th, and $^{226}$Ra. The exception is $^{234}$U, which is second generation in one chain and first generation in another chain. The radionuclide mass input to the 1-D SZ Flow and Transport Abstraction comes from the UZ Transport Submodel. As documented in the parent document, this mass is fed to both the 1-D and 3-D SZ Flow and Transport Abstractions. The radionuclide mass for all species is tracked in both the 1-D and 3-D SZ Flow and Transport Abstractions. As a response to the issue identified in Section P15 of the parent document and for the analyses documented in this addendum, no mass is passed from the UZ Transport Submodel to the 1-D SZ Flow and Transport Abstraction for the following radionuclides: $^{231}$Pa, $^{229}$Th, $^{232}$Th, and $^{226}$Ra. The radionuclide mass exiting each submodel (3-D and 1-D) is then screened such that, for the biosphere calculation, only the mass from the 1-D SZ Flow and Transport Abstraction is used for the second-generation daughter species $^{235}$U, $^{233}$U, and $^{230}$Th. In addition, for the biosphere calculations, the mass of the daughter products $^{231}$Pa, $^{229}$Th, $^{232}$Th, and $^{226}$Ra created along the transport pathway due to decay of their parent species from the 1-D SZ Flow and Transport Submodel is summed with the mass from the 3-D SZ Flow and Transport Submodel. The 3-D SZ Flow and Transport Submodel is used to transport the radionuclide mass that is passed from the UZ Transport Submodel. For these four species, no mass is passed from the UZ Transport Submodel to the 1-D SZ Flow and Transport Submodel, so the output from the 1-D SZ Flow and Transport Submodel contains only the mass of the daughter products. All the other radionuclide biosphere calculations utilize the output from the 3-D SZ Flow and Transport Abstraction. The disposition of SZ submodel mass is shown in Table 6.3.10-8[a].

Even though they are accounted for in the 3-D SZ Flow and Transport Abstraction, the parents of the second-generation daughters are also transported in the 1-D SZ Flow and Transport Abstraction. The parents are included in the 1-D SZ Flow and Transport Abstraction to account for the ingrowth of the second-generation daughters.
6.3.10.4[a] Model Component Consistency and Conservatism in Assumptions and Parameters

No change.

6.3.10.5[a] Alternative Conceptual Model(s) for Saturated Zone Flow and Transport

No change.
### Table 6.3.10-8[a]. Radionuclide Species Mass Passed to the Biosphere Submodel

<table>
<thead>
<tr>
<th>Radionuclide Group</th>
<th>3-D SZ Flow and Transport Submodel</th>
<th>1-D SZ Flow and Transport Submodel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fission Products</td>
<td>$^{14}$C, $^{36}$Cl, $^{79}$Se, $^{90}$Sr, $^{99}$Tc, $^{126}$Sn, $^{128}$I, $^{129}$I, $^{135}$Cs, $^{137}$Cs, $^{232}$U</td>
<td>None</td>
</tr>
<tr>
<td>Actinium Decay Chains</td>
<td>$^{243}$Am, $^{239}$Pu, $^{231}$Pa</td>
<td>$^{235}$U, $^{231}$Pa$^a$</td>
</tr>
<tr>
<td>Actinium Series</td>
<td>$^{241}$Am, $^{237}$Np, $^{229}$Th</td>
<td>$^{233}$U, $^{229}$Th$^a$</td>
</tr>
<tr>
<td>Neptunium Series</td>
<td>$^{240}$Pu, $^{236}$U, $^{232}$Th</td>
<td>$^{232}$Th$^a$</td>
</tr>
<tr>
<td>Thorium Series</td>
<td>$^{242}$Pu, $^{238}$U, $^{238}$Pu, $^{234}$U, $^{226}$Ra</td>
<td>$^{230}$Th, $^{226}$Ra$^a$</td>
</tr>
<tr>
<td>Uranium Series</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^a$ Denotes only the radionuclide mass produced as a result of ingrowth (e.g., only the daughter product mass is counted for these species).
INTENTIONALLY LEFT BLANK
Total System Performance Assessment Model/Analysis for the License Application

Source: DTNs: MO0702PASTREAM.001_R0 [DIRS 179925], File: DTN-Inventory-Rev00.xls; and SNO710PASZFTMA.003_R0 [DIRS 183485], File: Radionuclides_1D_3D.doc.

NOTES: 
(a) denotes half-life values used in the1-D Transport Model taken from DTN: MO0702PASTREAM.001_R0 [DIRS 179925]; (b) denotes the mass created by ingrowth from actinide decay in the 1-D SZ Flow and Transport Abstraction for $^{231}\text{Pa}$, $^{229}\text{Th}$, $^{232}\text{Th}$, and $^{226}\text{Ra}$ are added to the radionuclide mass for these species from the 3-D SZ Transport model, the combined mass is used as the input to the Biosphere Submodel calculations (Section 6.3.10.3[a]). The Biosphere Submodel calculations use the mass released from the SZ 1-D Transport Model for radionuclides $^{235}\text{U}$, $^{233}\text{U}$, and $^{230}\text{Th}$ as indicated by the shaded areas. The Biosphere Submodel calculations use the mass released from the 3-D SZ Flow and Transport Abstraction for all other radionuclides (see Section 6.3.10[a] for details).

Figure 6.3.10-8[a]. Radionuclide Decay Chains Considered in Saturated Zone Transport Calculations
INTENTIONALLY LEFT BLANK
6.3.11[a]  Biosphere

No change.

6.4[a]  TSPA-LA MODEL FOR THE EARLY FAILURE SCENARIO CLASS

No change.

6.5[a]  TSPA-LA MODEL FOR THE IGNEOUS SCENARIO CLASS

No change.

6.6[a]  TSPA-LA MODEL FOR THE SEISMIC SCENARIO CLASS

The analyses documented in this addendum include changes necessary to reflect the removal of a non-physical and conservative treatment of WP damage from seismic events following the first breach due to nominal corrosion processes as documented in Appendix P of the parent document, specifically Section P3. In addition, issues identified on Table P-6 of the parent document, Items 3, 4, and 14, have been addressed in TSPA-LA Model v5.005 (see Appendix P[a] for a list of the issues addressed in this addendum). Sections 6.6.1.3.7[a] and 6.6.1.3.8[a] outline the modifications necessary for the revised treatment of WP damage from seismic events used in TSPA-LA Model v5.005. In addition, the caption for Figure 6.6-13 in the parent document has been revised and is included as Figure 6.6-13[a]. Section 6.6.2.4[a] contains an update to two paragraphs that incorrectly documented the implementation of the Localized Corrosion Submodel for the Seismic Scenario Class.

6.6.1[a]  TSPA-LA Model Components and Submodels for the Seismic Scenario Class

The subsections included in this addendum outline only the model implementation descriptions that have changed from those presented in the parent document.

6.6.1.1[a]  Conceptual Model for Seismic Response of the Engineered Barrier System

No change.

6.6.1.2[a]  Abstraction Model for Seismic Response of the Engineered Barrier System

No change.

6.6.1.3[a]  Implementation in the TSPA-LA Model

Sections 6.6.1.3.1, 6.6.1.3.7, and 6.6.1.3.8 of the parent document have been updated to provide corrected descriptions and to reflect model changes for TSPA-LA Model v5.005.

6.6.1.3.1[a]  TSPA-LA Modeling Cases

The aleatory parameter set used to calculate mean annual dose in the Seismic GM Modeling Case for 10,000 years was not reported correctly in the parent document. Table 6.6-3[a] shows
the correct values for this modeling case. These corrections are described in the following paragraph.

**Seismic GM Modeling Case**

For each element in the Latin hypercube sample, the expected annual dose history is calculated by Equation 6.1.2-22 of the parent document, using the annual dose histories computed for each element of the Latin hypercube sample. The integral in Equation 6.1.2-22 of the parent document accounts for the uncertainty in the number of seismic events, the time of each event, and the damaged area. Table 6.6-3[a] summarizes these parameters for the Seismic GM Modeling Case (10,000 years), including the correct time for the first seismic event (200 years) and one additional CDSP damage fraction of 0.0001, which was inadvertently omitted from the parent document.

6.6.1.3.2[a] **Seismic Event Time and Magnitude Calculations for the 1,000,000-Year Ground Motion Case**

No change.

6.6.1.3.3[a] **Methodology for Damage Abstraction Implementation**

No change.

6.6.1.3.4[a] **Implementation of Rockfall for the 1,000,000-Year Ground Motion Case**

No change.

6.6.1.3.5[a] **Implementation of Drip Shield Plate and Framework Damage from Ground Motion**

No change.

6.6.1.3.6[a] **Implementation of Waste Package Rupture and Puncture from Ground Motion**

No change.

6.6.1.3.7[a] **Implementation of Waste Package Stress Corrosion Cracking Damage from Ground Motion**

The probability of seismic damage is provided for two end-member states of the WP—one with intact internals and one with fully degraded internals. In TSPA-LA Model v5.000, once any WP is breached by a nominal process in a given percolation subregion (e.g., from first occurrence of stress corrosion cracks located on the outer lids), the probability of seismic damage is switched from the intact internals abstraction to the fully degraded internals abstraction for all WPs in a given percolation subregion. This implementation selection increases the chance of seismic damage occurring while the DS is intact, which is conservative, as most of the WPs have not yet failed by the nominal processes and should be using the intact internals damage probability.
(as documented in Appendix P, Section P3, of the parent document). In TSPA-LA Model v5.005, documented in this addendum, the implementation has been modified as outlined below to track the fraction of packages with degraded internals (e.g., WPs that have been breached) and apply the seismic WP damage proportionally over each repository percolation subregion. The description of the implementation for the probability of WP damage for both end-member states and the calculation of WP damage area, as presented in Section 6.6.1.3.7 of the parent document, remains unchanged.

The abstractions for the probability of WP damage and for the conditional damaged area are functions of whether or not the WP internals are degraded. The internals are considered non-degraded until an intact package is breached by a seismic event or nominal corrosion process. If WP failure, due to nominal corrosion processes, occurs before the first seismic damage event, the calculation of probability of seismic damage is switched from the intact internals abstraction to the fully degraded internals abstraction, which increases the chance of seismic damage occurring. Damage from seismic events is accumulated and applied only to those WPs that are failed. When either a seismic event occurs that is large enough to damage all the WPs (including those that have not failed) or all of the WPs have been breached by nominal corrosion processes, the accumulated seismic damage area is applied to all WPs in the percolation subregion.

6.6.1.3.8[a] Waste Package Thickness Calculations

In Section 6.6.1.3.8 of the parent document, the abstraction for the probability of damage for CSNF WPs surrounded by rubble used results for a 17-mm WP outer corrosion barrier (OCB) thickness to obtain a conservative estimate of the probability of first failure time of a CSNF WP surrounded by rubble. The same approximation is used for CDSP WPs if the WP damage does not occur before DS failure. The 17-mm abstraction was applied to determine the time of first failure for a WP surrounded by rubble regardless of the time-dependent thickness of the WPs in TSPA-LA Model v5.000. In TSPA-LA Model v5.005, this conservatism is no longer applied. The first damage time to WPs surrounded by rubble is calculated using both the 17-mm and 23-mm thickness abstractions. In addition, in TSPA-LA Model v5.000, WP puncture was omitted as a mechanism contributing to the time of first WP failure because of the low probability of puncture occurring (Appendix P of the parent document, Table P-6, Item 14). In TSPA-LA Model v5.005, this omission has been corrected as outlined in the paragraphs below.

WPs and overlying DSs are partitioned among the five percolation subregions according to the partitioning described in Section 6.3.2.2.1. In the Seismic GM Modeling Case, the calculations for the probability of damage and damaged area are a function of WP OCB thickness, which depends on the general corrosion rate of Alloy 22. The general corrosion calculation depends on temperature, and other parameters that vary at the percolation subregion level and with fuel type (Section 6.3.5.1.2). Therefore, the time-dependent WP OCB thickness will be different for each of the five percolation subregions and for each of the two fuel types.

The general corrosion rate of the Titanium Grade 7 DSs is given by a distribution that is independent of percolation subregion parameters and will be the same for all DSs (Section 6.3.5.1.2).
The abstractions for WP degradation used in the Seismic GM Modeling Case require the spatially-averaged thickness of the WP OCB as a function of time. This calculation is done as part of the WP and DS Degradation Submodel calculations. The WAPDEG V4.07 software is run 10 times, once for each percolation subregion and fuel type, to produce a time history of WP thickness. This calculation is done separately from the calculation of WP breach used to feed the EBS Flow and Transport Model Component (Sections 6.3.6 and 6.3.8) for nominal corrosion processes. The general corrosion rate used for the feed to the Seismic GM Modeling Cases is done with an average rate rather than an extreme patch approximation to the general corrosion rate discussed in Section 6.3.5.1.2. The method discussed in Section 6.3.5.1.2 used the highest of four sampled corrosion rates (from the two-parameter Weibull distribution) to analyze general corrosion of the WP patch. For the purposes of the seismic abstractions, the average of the four sampled corrosion rates was used to generate the general corrosion rate fed to the WAPDEG V4.07 software (output DTN: MO0707WPDRIPSD.000 [DIRS 183005]). The GetThk_LA V1.0 (STN: 11229-1.0-00 [DIRS 181040]) software was used to post-process the thickness file output by the WAPDEG V4.07 software and generate a one-dimensional table of mean WP OCB thickness versus time. This mean thickness is a spatially-averaged WP OCB thickness over all the WPs in a particular percolation subregion for each fuel type.

Since the nominal corrosion processes calculated by the WAPDEG V4.07 software calculations are included in the Seismic GM Modeling Case, the calculations must account for inside-out corrosion that occurs after a seismic event has damaged a WP. The mean time of the first seismic event that causes WP damage is an input to the WAPDEG V4.07 calculations. However, the WAPDEG V4.07 calculations are done at the beginning of the simulation, before any seismic calculations are done. Therefore, a separate \textit{a priori} calculation of the time that WPs are first damaged by a seismic event is carried out.

The calculation of the first damage time is performed \textit{a priori} in the Aleatory Parameters and Dynamic Calculations GoldSim Submodel. The calculation generates a history of seismic events and evaluates whether or not each event causes WPs to fail. The time of the event that causes the first failure for each fuel type and percolation subregion is recorded as an output of the calculation. The calculation considers whether the WPs are under an intact DS or are surrounded by rubble. If the WPs are surrounded by rubble, the calculations evaluate whether or not stress corrosion crack damage or punctures occur.

CSNF and CDSP WPs are considered to have intact internals before the first seismic damage event and the probability of damage for WPs with intact internals under intact DSs is not a function of WP thickness (Figures 6.6-10 and 6.6-11; and DTN: MO0703PASEISDA.002_R4 [DIRS 183156], Tables 1-4 and 1-6). However, for CSNF WPs, damage is not likely to occur before DS failure. Therefore, for CSNF WPs, the abstraction for the probability of damage for WPs surrounded by rubble is dependent on the thickness of the WPs (Figure 6.6-15; and DTN: MO0703PASEISDA.002_R4 [DIRS 183156], Table 1-8). For each percolation subregion and fuel type, time histories for the average WP thickness under nominal conditions are generated when the Nominal Scenario Class is performed. These histories are used to determine the time of first WP damage in the Seismic Scenario Class when the DS plates have failed and the WP is surrounded by rubble.
6.6.2[a] Interaction of Seismic Scenario Class Submodels with other TSPA-LA Submodels

In the parent document, Section 6.6.2.4, Waste Package Localized Corrosion Initiation Submodel for Seismic Disruption, the title of this subsection was misleading and the first and second paragraphs contained incorrect information concerning the environmental conditions that can support initiation of localized corrosion. In addition, Section 6.6.2.4 of the parent document omitted a cross-reference to the supporting localized corrosion initiation analyses documented in Appendix O of the parent document. Section 6.6.2.4[a] of this addendum, now titled Waste Package Localized Corrosion Initiation Submodel Implementation for Seismic Disruption, includes the corrected version of only the first two paragraphs of Section 6.6.2.4. These paragraphs should be used in replacement of the first two paragraphs included in Section 6.6.2.4 of the parent document. These changes are strictly due to the documentation and do not represent any model changes from TSPA-LA Model v5.000. The conclusions and analyses presented in the parent document remain unchanged.

6.6.2.1[a] Drift Seepage Submodel and Drift Wall Condensation Submodel Modification for Seismic Disruption

No change.

6.6.2.2[a] Engineered Barrier System Thermal-Hydrologic Environment Submodel Modification for Seismic Disruption

No change.

6.6.2.3[a] Waste Package and Drip Shield Degradation Submodel Modifications for Seismic Disruption

No change.

6.6.2.4[a] Waste Package Localized Corrosion Initiation Submodel Implementation for Seismic Disruption

The Seismic Scenario Class does not include the potential effect of crown-seepage initiated localized corrosion on the WP outer surface. Although crown-seepage induced localized corrosion is possible for both the Seismic GM and FD Modeling Cases, a stand-alone localized corrosion initiation analysis has been carried out to determine if the environmental conditions required for localized corrosion initiation are present only for approximately 12,000 years after repository closure (Figure O-2 of the parent document). Beyond this time, the chemistry of the seepage water is benign, and localized corrosion no longer occurs (Section O3 of the parent document). This stand-alone analysis is documented in Section 6.3.5.2. The temperature, pH, chloride-ion concentration, and nitrate-ion concentration in aqueous solutions on the WP outer surface are the primary factors that determine the potential for initiating localized corrosion. In addition, localized corrosion can only occur if crown seepage water contacts the WP outer surface (i.e., if the DS is failed).
In the Seismic GM Modeling Case simulations, there is a low probability (Figure 7.3.2-16 of the parent document) of DS plate failure occurring before 12,000 years. Section 7.3.2.6.1.3.2 of the parent document discusses the justification for not considering localized corrosion due to these early DS failures. In the Seismic FD Modeling Case simulations, DSs can be failed at early times where environmental conditions are suitable for localized corrosion initiation. However, it is assumed that the added damage due to the fault displacement is sufficient to account for the effects of localized corrosion. This assumption has been verified by simulation runs showing that the dose is insensitive to increasing the fraction of the damaged area beyond 1/3 of the WP cross-sectional area (Section 7.3.2.7 and Figure 7.3.2-25 of the parent document).

**6.6.3[a] Model Component Consistency and Conservatisms in Assumptions and Parameters**

No change.

**6.6.4[a] Alternative Conceptual Model(s) for Seismic Scenario Modeling Cases**

No change.
### Table 6.6-3[a]. Seismic Ground Motion and Fault Displacement Modeling Cases Using Pre-Specified Parameters

<table>
<thead>
<tr>
<th>Modeling Case</th>
<th>Seismic Event Time (yr)</th>
<th>CSNF WP Damage Fraction (fraction of WP surface area)</th>
<th>CDSP WP Damage Fraction (fraction of WP surface area)</th>
<th>Number of Failed CSNF WPs</th>
<th>Number of Failed CDSP WPs</th>
<th>Rubble Volume Accumulated (m³/m)</th>
<th>Rubble Fill Time (yr)</th>
<th>DS Damage Fraction (fraction of WP surface area)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seismic 1M year FD Casea</td>
<td>1,000 20,000 80,000 200,000 400,000 800,000</td>
<td>0.028 0.056 0.084</td>
<td>0.0335 0.067 0.101</td>
<td>0</td>
<td>100</td>
<td>100</td>
<td>120</td>
<td>Seismic Event Time</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.0</td>
</tr>
<tr>
<td>Seismic 10k year FD Caseb</td>
<td>200 800 2,000 4,000 8,000 18,000</td>
<td>0.028 0.056 0.084</td>
<td>0.0335 0.067 0.101</td>
<td>0</td>
<td>100</td>
<td>100</td>
<td>120</td>
<td>Seismic Event Time</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.0</td>
</tr>
<tr>
<td>Seismic 10k year GM Casec</td>
<td>200 1,000 3,000 6,000 12,000 18,000</td>
<td>0</td>
<td>1.00x10⁻⁷ 1.00x10⁻⁴ 0.00001 0.0001 0.001</td>
<td>0</td>
<td>3416</td>
<td>0</td>
<td>2,000,000</td>
<td>0.0</td>
</tr>
<tr>
<td>Seismic 1M yr GM Case</td>
<td>Section 6.6.1.3.1</td>
<td>Section 6.6.1.3.4</td>
<td>Section 6.6.1.3.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source:  
- a Output DTN: MO0708TSPAGENT.000 [DIRS 183000], folder: PL-TSPA-DTN-9 (PEF 126)  
- b Output DTN: MO0708TSPAGENT.000 [DIRS 183000], folder: PL-TSPA-DTN-8 (PEF 125)  
- c Output DTN: MO0708TSPAGENT.000 [DIRS 183000], folder: PL-TSPA-DTN-7 (PEF 124)

**NOTE:** For each modeling case run defined above, the model cycles through all possible combinations of the aleatory parameters one realization at a time, holding the epistemic sample number constant. For the Seismic FD Case (1,000,000 years) and the Seismic FD Case (10,000 years), there are 108 possible combinations of aleatory parameters. For the Seismic GM Case (10,000 years) there are 30 possible combinations of aleatory parameters.
Figure 6.6-13[a]. Quadratic Fit for Mean Damaged Area on a CDSP WP under an Intact Drip Shield: (a) 23-mm WP Outer Barrier with Intact Internals, (b) 23-mm WP Outer Barrier with Degraded Internals, and (c) 17-mm WP Outer Barrier with Degraded Internals.
INTENTIONALLY LEFT BLANK
6.7[a] TSPA-LA MODEL FOR THE HUMAN INTRUSION SCENARIO

No change.
INTENTIONALLY LEFT BLANK
Total System Performance Assessment
Model/Analysis for the License Application
Addendum 01

Volume II

Prepared for:
U.S. Department of Energy
Office of Civilian Radioactive Waste Management
Office of Repository Development
1551 Hillshire Drive
Las Vegas, Nevada 89134-6321

Prepared by:
Sandia National Laboratories
OCRWM Lead Laboratory for Repository Systems
1180 Town Center Drive
Las Vegas, Nevada 89144

Under Contract Number
DE-AC04-94AL85000
DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, nor any of their contractors, subcontractors or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or any third party’s use or the results of such use of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof or its contractors or subcontractors. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.
## CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>7[a]. MODEL VALIDATION AND CONFIDENCE BUILDING</td>
<td>7-1[a]</td>
</tr>
<tr>
<td>7.1[a] MODEL VALIDATION STRATEGY</td>
<td>7-3[a]</td>
</tr>
<tr>
<td>7.2[a] COMPUTER CODE AND INPUT VERIFICATION</td>
<td>7-13[a]</td>
</tr>
<tr>
<td>7.2.1[a] Selection and Verification of the Integrated System Software: GoldSim</td>
<td>7-13[a]</td>
</tr>
<tr>
<td>7.2.2[a] Verification of Dynamically Linked Libraries as Single Modules and in an Integrated System</td>
<td>7-13[a]</td>
</tr>
<tr>
<td>7.2.3[a] Verification of Inputs in Total System Performance Assessment Input Database</td>
<td>7-13[a]</td>
</tr>
<tr>
<td>7.2.4[a] Verification of Single Model Components</td>
<td>7-14[a]</td>
</tr>
<tr>
<td>7.2.5[a] Verification of Coupling among Submodels and Model Components</td>
<td>7-17[a]</td>
</tr>
<tr>
<td>7.2.6[a] Verification of Range of Applicability of Submodels and Model Components</td>
<td>7-17[a]</td>
</tr>
<tr>
<td>7.3[a] MODEL STABILITY</td>
<td>7-18[a]</td>
</tr>
<tr>
<td>7.3.1[a] Statistical Stability</td>
<td>7-18[a]</td>
</tr>
<tr>
<td>7.3.2[a] Numerical Accuracy of Expected Annual Dose</td>
<td>7-31[a]</td>
</tr>
<tr>
<td>7.3.3[a] Temporal Stability</td>
<td>7-33[a]</td>
</tr>
<tr>
<td>7.3.4[a] Analyses of Spatial Discretization</td>
<td>7-39[a]</td>
</tr>
<tr>
<td>7.3.5[a] Stability of FEHM Particle Tracking Model</td>
<td>7-39[a]</td>
</tr>
<tr>
<td>7.4[a] UNCERTAINTY AND VARIABILITY CHARACTERIZATION REVIEWS</td>
<td>7-39[a]</td>
</tr>
<tr>
<td>7.5[a] SURROGATE WASTE FORM VALIDATION</td>
<td>7-39[a]</td>
</tr>
<tr>
<td>7.5.1[a] Methodology</td>
<td>7-39[a]</td>
</tr>
<tr>
<td>7.5.2[a] Spent Fuel Categories and Representation in Model</td>
<td>7-39[a]</td>
</tr>
<tr>
<td>7.5.3[a] Naval Spent Fuel, Category 1</td>
<td>7-39[a]</td>
</tr>
<tr>
<td>7.5.4[a] U.S. Department of Energy Spent Fuel, Categories 2 through 11</td>
<td>7-42[a]</td>
</tr>
<tr>
<td>7.5.5[a] Selected Sensitivity Analyses</td>
<td>7-42[a]</td>
</tr>
<tr>
<td>7.5.6[a] Summary of Results for U.S. Department of Energy Spent Fuel</td>
<td>7-42[a]</td>
</tr>
<tr>
<td>7.6[a] CORROBORATION OF ABSTRACTION MODEL RESULTS WITH VALIDATED PROCESS MODELS</td>
<td>7-42[a]</td>
</tr>
<tr>
<td>7.7[a] CORROBORATION OF RESULTS WITH AUXILIARY ANALYSES</td>
<td>7-42[a]</td>
</tr>
<tr>
<td>7.7.1[a] Analyses of Single Realizations</td>
<td>7-43[a]</td>
</tr>
<tr>
<td>7.7.2[a] Comparison with Simplified TSPA Analysis</td>
<td>7-84[a]</td>
</tr>
<tr>
<td>7.7.3[a] Comparison with Electric Power Research Institute Analysis</td>
<td>7-86[a]</td>
</tr>
<tr>
<td>7.7.4[a] Performance Margin Analysis</td>
<td>7-88[a]</td>
</tr>
<tr>
<td>7.8[a] NATURAL ANALOGUES</td>
<td>7-90[a]</td>
</tr>
<tr>
<td>7.9[a] TECHNICAL REVIEWS SUMMARY</td>
<td>7-91[a]</td>
</tr>
<tr>
<td>7.10[a] SUMMARY OF MODEL CONFIDENCE BUILDING</td>
<td>7-91[a]</td>
</tr>
<tr>
<td>Section</td>
<td>Page</td>
</tr>
<tr>
<td>--------------------------------------------</td>
<td>--------</td>
</tr>
<tr>
<td>7.10.1[a] Validation Strategy</td>
<td>7-91[a]</td>
</tr>
<tr>
<td>7.10.2[a] Code and Input Verification</td>
<td>7-91[a]</td>
</tr>
<tr>
<td>7.10.3[a] Model Stability Testing</td>
<td>7-91[a]</td>
</tr>
<tr>
<td>7.10.4[a] Uncertainty Characterization Review and Sensitivity Analyses</td>
<td>7-93[a]</td>
</tr>
<tr>
<td>7.10.5[a] Surrogate Waste Form Validation</td>
<td>7-93[a]</td>
</tr>
<tr>
<td>7.10.6[a] Corroboration of Abstraction Results with Validated Process Models</td>
<td>7-93[a]</td>
</tr>
<tr>
<td>7.10.7[a] Corroboration of Results with Auxiliary Analyses</td>
<td>7-93[a]</td>
</tr>
<tr>
<td>7.10.8[a] Corroboration of Results with Natural Analogues</td>
<td>7-95[a]</td>
</tr>
<tr>
<td>7.10.9[a] Technical Reviews Summary</td>
<td>7-95[a]</td>
</tr>
<tr>
<td>7.10.10[a] Conclusions</td>
<td>7-95[a]</td>
</tr>
</tbody>
</table>

CONTENTS (Continued)
### FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.2-17[a]</td>
<td>Cumulative Releases of $^{129}$I, $^{237}$Np, and $^{233}$U from the Human Intrusion Borehole Based on Simulations Considering and not Considering Matrix Diffusion</td>
</tr>
<tr>
<td>7.3.1-14[a]</td>
<td>Stability of Human Intrusion Scenario: (a) Comparison of Expected Annual Dose for Three Replicates and (b) Confidence Interval around Mean Annual Dose</td>
</tr>
<tr>
<td>7.3.1-17[a]</td>
<td>Expected Annual Dose for 1,000,000 Years for the Nominal Modeling Case from (a) TSPA-LA Model v5.000 and (b) TSPA-LA Model v5.005</td>
</tr>
<tr>
<td>7.3.1-18[a]</td>
<td>Comparison of Statistics for Expected Annual Dose in the Nominal Modeling Case between TSPA-LA Model v5.000 and TSPA-LA Model v5.005</td>
</tr>
<tr>
<td>7.3.1-19[a]</td>
<td>Comparison of Expected Annual Dose for Individual Sample Elements in the Nominal Modeling Case between TSPA-LA Model v5.000 and TSPA-LA Model v5.005 at (a) 400,000; (b) 600,000; (c) 800,000; and (d) 1,000,000 Years</td>
</tr>
<tr>
<td>7.3.1-20[a]</td>
<td>Comparison of Statistics for Expected Annual Dose over 20,000 Years in the Drip Shield Early Failure Modeling Case between TSPA-LA Model v5.000 and TSPA-LA Model v5.005</td>
</tr>
<tr>
<td>7.3.1-21[a]</td>
<td>Comparison of Statistics for Expected Annual Dose over 1,000,000 Years in the Drip Shield Early Failure Modeling Case between TSPA-LA Model v5.000 and TSPA-LA Model v5.005</td>
</tr>
<tr>
<td>7.3.1-22[a]</td>
<td>Comparison of Expected Annual Dose for Individual Sample Elements in the Drip Shield Early Failure Modeling Case between TSPA-LA Model v5.000 and TSPA-LA Model v5.005 at (a) 1,000; (b) 3,000; (c) 5,000; and (d) 10,000 Years</td>
</tr>
<tr>
<td>7.3.1-23[a]</td>
<td>Comparison of Expected Annual Dose for Individual Sample Elements in the Drip Shield Early Failure Modeling Case between TSPA-LA Model v5.000 and TSPA-LA Model v5.005 at (a) 100,000; (b) 200,000; (c) 600,000; and (d) 1,000,000 Years</td>
</tr>
<tr>
<td>7.3.1-24[a]</td>
<td>Comparison of Statistics for Expected Annual Dose over 20,000 Years in the Waste Package Early Failure Modeling Case between TSPA-LA Model v5.000 and TSPA-LA Model v5.005</td>
</tr>
<tr>
<td>7.3.1-25[a]</td>
<td>Comparison of Statistics for Expected Annual Dose over 1,000,000 Years in the Waste Package Early Failure Modeling Case between TSPA-LA Model v5.000 and TSPA-LA Model v5.005</td>
</tr>
<tr>
<td>7.3.1-26[a]</td>
<td>Comparison of Expected Annual Dose for Individual Sample Elements in the Waste Package Early Failure Modeling Case between TSPA-LA Model v5.000 and TSPA-LA Model v5.005 at (a) 1,000; (b) 3,000; (c) 5,000; and (d) 10,000 Years</td>
</tr>
</tbody>
</table>
7.3.1-27[a]. Comparison of Expected Annual Dose for Individual Sample Elements in the Waste Package Early Failure Modeling Case between TSPA-LA Model v5.000 and TSPA-LA Model v5.005 at (a) 100,000; (b) 200,000; (c) 600,000; and (d) 1,000,000 Years ............... F7.3-12[a]

7.3.1-28[a]. Comparison of Statistics for Expected Annual Dose over 20,000 Years in the Igneous Intrusion Modeling Case between TSPA-LA Model v5.000 and TSPA-LA Model v5.005 .......................... F7.3-13[a]

7.3.1-29[a]. Comparison of Statistics for Expected Annual Dose over 1,000,000 Years in the Igneous Intrusion Modeling Case between TSPA-LA Model v5.000 and TSPA-LA Model v5.005 .......................... F7.3-14[a]

7.3.1-30[a]. Comparison of Expected Annual Dose for Individual Sample Elements in the Igneous Intrusion Modeling Case between TSPA-LA Model v5.000 and TSPA-LA Model v5.005 at (a) 1,000; (b) 3,000; (c) 5,000; and (d) 10,000 Years ................................. F7.3-15[a]

7.3.1-31[a]. Comparison of Expected Annual Dose for Individual Sample Elements in the Igneous Intrusion Modeling Case between TSPA-LA Model v5.000 and TSPA-LA Model v5.005 at (a) 100,000; (b) 200,000; (c) 600,000; and (d) 1,000,000 Years .............. F7.3-16[a]

7.3.1-32[a]. Comparison of Statistics for Expected Annual Dose over 20,000 Years in the Seismic Ground Motion Modeling Case between TSPA-LA Model v5.000 and TSPA-LA Model v5.005 .......................... F7.3-17[a]

7.3.1-33[a]. Comparison of Expected Annual Dose for Individual Sample Elements in the Seismic Ground Motion Modeling Case between TSPA-LA Model v5.000 and TSPA-LA Model v5.005 at (a) 1,000; (b) 3,000; (c) 5,000; and (d) 10,000 Years ................................. F7.3-18[a]

7.3.1-34[a]. Expected Annual Dose for 1,000,000 Years for the Seismic Ground Motion Modeling Case from (a) TSPA-LA Model v5.000 and (b) TSPA-LA Model v5.005 ........................................................................ F7.3-19[a]

7.3.1-35[a]. Comparison of Statistics for Expected Annual Dose over 1,000,000 Years in the Seismic Ground Motion Modeling Case between TSPA-LA Model v5.000 and TSPA-LA Model v5.005 ............... F7.3-20[a]

7.3.1-36[a]. Comparison of Expected Annual Dose for Individual Sample Elements in the Seismic Ground Motion Modeling Case between TSPA-LA Model v5.000 and TSPA-LA Model v5.005 at (a) 100,000; (b) 200,000; (c) 600,000; and (d) 1,000,000 Years .............. F7.3-21[a]

7.3.1-37[a]. Comparison of Statistics for Expected Annual Dose over 20,000 Years in the Seismic Fault Displacement Modeling Case between TSPA-LA Model v5.000 and TSPA-LA Model v5.005 .......................... F7.3-22[a]

7.3.1-38[a]. Comparison of Statistics for Expected Annual Dose over 1,000,000 Years in the Seismic Fault Displacement Modeling Case between TSPA-LA Model v5.000 and TSPA-LA Model v5.005 ............... F7.3-23[a]
7.3.1-39[a]. Comparison of Expected Annual Dose for Individual Sample Elements in the Seismic Fault Displacement Modeling Case between TSPA-LA Model v5.000 and TSPA-LA Model v5.005 at (a) 1,000; (b) 3,000; (c) 5,000; and (d) 10,000 Years .............................................. F7.3-24[a]

7.3.1-40[a]. Comparison of Expected Annual Dose for Individual Sample Elements in the Seismic Fault Displacement Modeling Case between TSPA-LA Model v5.000 and TSPA-LA Model v5.005 at (a) 100,000; (b) 200,000; (c) 600,000; and (d) 1,000,000 Years ............ F7.3-25[a]

7.3.1-41[a]. Total Expected Annual Dose for 10,000 Years from (a) TSPA-LA Model v5.000 and (b) TSPA-LA Model v5.005 .......................................................... F7.3-26[a]

7.3.1-42[a]. Comparison of Statistics for Total Expected Annual Dose over 20,000 Years between TSPA-LA Model v5.000 and TSPA-LA Model v5.005 ................................................. F7.3-27[a]

7.3.1-43[a]. Comparison of Total Expected Annual Dose for Individual Sample Elements between TSPA-LA Model v5.000 and TSPA-LA Model v5.005 at (a) 1,000; (b) 3,000; (c) 5,000; and (d) 10,000 Years ............ F7.3-28[a]

7.3.1-44[a]. Total Expected Annual Dose for 1,000,000 Years from (a) TSPA-LA Model v5.000 and (b) TSPA-LA Model v5.005.......................................................... F7.3-29[a]

7.3.1-45[a]. Comparison of Statistics for Total Expected Annual Dose over 1,000,000 Years between TSPA-LA Model v5.000 and TSPA-LA Model v5.005 ................................................. F7.3-30[a]

7.3.1-46[a]. Comparison of Total Expected Annual Dose for Individual Sample Elements between TSPA-LA Model v5.000 and TSPA-LA Model v5.005 at (a) 100,000; (b) 200,000; (c) 600,000; and (d) 1,000,000 Years ........................................................................ F7.3-31[a]

7.3.1-47[a]. Confidence Interval for Total Mean Annual Dose for 20,000 Years for (a) TSPA-LA Model v5.000 and (b) TSPA-LA Model v5.005 Computed with the Bootstrap Technique ............................................. F7.3-32[a]

7.3.1-48[a]. Confidence Interval for Total Mean Annual Dose for 1,000,000 Years for (a) TSPA-LA Model v5.000 and (b) TSPA-LA Model v5.005 Computed with the Bootstrap Technique ............................................. F7.3-33[a]

7.3.3-10[a]. Expected Annual Dose from a Human Intrusion at 200,000 Years for Two Timestep Schemes .......................................................................................... F7.3-34[a]

7.3.3-11[a]. Detail of Expected Annual Dose from a Human Intrusion at 200,000 Years for Two Timestep Schemes .......................................................................................... F7.3-35[a]

7.3.3-12[a]. Expected Annual Dose for 1,000,000 Years for the Nominal Modeling Case from (a) TSPA-LA Model v5.005 and (b) Alternative Timestep Scheme ............................................. F7.3-36[a]

7.3.3-13[a]. Expected Annual Dose Statistics for 1,000,000 Years for the Nominal Modeling Case Using Two Timestep Schemes ............................................. F7.3-37[a]
<table>
<thead>
<tr>
<th>FIGURES (Continued)</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.5-4[a]. Comparison of Mean Annual Dose for a Single CSNF WP and a Single Waste Package with a Naval Source Term for the Drip Shield Early Failure Modeling Case</td>
<td>F7.5-1[a]</td>
</tr>
<tr>
<td>7.5-5[a]. Comparison of Mean Annual Dose for a Single CSNF WP and Single WP with a Naval Source Term for the Igneous Intrusion Modeling Case</td>
<td>F7.5-2[a]</td>
</tr>
<tr>
<td>7.7.1-1[a]. Expected Annual Dose from 300 Epistemic Vectors, Along with their Quantiles and Expected Dose from Epistemic Vector 281 for the Waste Package Early Failure Modeling Case for 1,000,000 Years after Repository Closure: (a) Linear Time and (b) Log Time</td>
<td>F7.7-1[a]</td>
</tr>
<tr>
<td>7.7.1-2[a]. Annual Dose from Realizations 5601 through 5620 of the Waste Package Early Failure Modeling Case for 1,000,000 Years after Repository Closure</td>
<td>F7.7-2[a]</td>
</tr>
<tr>
<td>7.7.1-3[a]. Major Radionuclide Contributors to Mean Annual Dose for the Waste Package Early Failure Modeling Case for 1,000,000 Years after Repository Closure</td>
<td>F7.7-3[a]</td>
</tr>
<tr>
<td>7.7.1-4[a]. Major Radionuclide Contributors to Annual Dose for Realization 5608 of the Waste Package Early Failure Modeling Case for 1,000,000 Years after Repository Closure</td>
<td>F7.7-4[a]</td>
</tr>
<tr>
<td>7.7.1-5[a]. (a) Release Rates of Technetium from the Waste Form, EBS, Unsaturated Zone, and Saturated Zone for Realization 5608 and (b) Saturated Zone Breakthrough Curves of Technetium and Plutonium for Epistemic Uncertainty Vector 281 of the Waste Package Early Failure Modeling Case for 1,000,000 Years after Repository Closure</td>
<td>F7.7-5[a]</td>
</tr>
<tr>
<td>7.7.1-6[a]. (a) Release Rates and (b) Concentration of $^{239}$Pu for Realization 5608 of the Waste Package Early Failure Modeling Case for 1,000,000 Years after Repository Closure</td>
<td>F7.7-6[a]</td>
</tr>
<tr>
<td>7.7.1-7[a]. (a) Dissolved Concentrations of Plutonium in the CSNF Waste Form Domain for Realization 5608 and (b) CSNF Waste Form Domain Chemistry for Realization 5608 of the Waste Package Early Failure Modeling Case for 1,000,000 Years after Repository Closure</td>
<td>F7.7-7[a]</td>
</tr>
<tr>
<td>7.7.1-8[a]. Corrosion Product Sorption Coefficients ($K_{ds}$) and In-package pH for Realization 5608 of the Waste Package Early Failure Modeling Case for 1,000,000 Years after Repository Closure</td>
<td>F7.7-8[a]</td>
</tr>
<tr>
<td>7.7.1-9[a]. (a) Release Rates and (b) Concentration of $^{242}$Pu for Realization 5608 of the Waste Package Early Failure Modeling Case for 1,000,000 Years after Repository Closure</td>
<td>F7.7-9[a]</td>
</tr>
<tr>
<td>7.7.1-10[a]. Major Radionuclide Contributors to Annual Dose for Realization 5618 of the Waste Package Early Failure Modeling Case for 1,000,000 Years after Repository Closure</td>
<td>F7.7-10[a]</td>
</tr>
<tr>
<td>FIGURES (Continued)</td>
<td>Page</td>
</tr>
<tr>
<td>-----------------------------------------------------------------------------------</td>
<td>------------</td>
</tr>
<tr>
<td>7.7.1-11[a]. Cumulative Release from HLW and DSNF Waste Forms for Realization 5618 of the Waste Package Early Failure Modeling Case for 1,000,000 Years after Repository Closure ............................................. F7.7-11[a]</td>
<td></td>
</tr>
<tr>
<td>7.7.1-12[a]. Release Rates of $^{99}$Tc from the Waste Form, Invert, Unsaturated Zone, and Saturated Zone for Realization 5618 of the Waste Package Early Failure Modeling Case for 1,000,000 Years after Repository Closure ................................................................................................................. F7.7-12[a]</td>
<td></td>
</tr>
<tr>
<td>7.7.1-13[a]. (a) Release Rates and (b) Concentration of $^{239}$Pu for Realization 5618 of the Waste Package Early Failure Modeling Case for 1,000,000 Years after Repository Closure ........................................................................................................................................ F7.7-13[a]</td>
<td></td>
</tr>
<tr>
<td>7.7.1-14[a]. (a) Dissolved Concentrations of Plutonium in the High-Level Radioactive Waste Domain and (b) DSNF Waste Form Domain Chemistry for Realization 5618 of the Waste Package Early Failure Modeling Case for 1,000,000 Years after Repository Closure ................................................................................................................................................ F7.7-14[a]</td>
<td></td>
</tr>
<tr>
<td>7.7.1-15[a]. (a) Release Rates and (b) Concentration of $^{242}$Pu for Realization 5618 of the Waste Package Early Failure Modeling Case for 1,000,000 Years after Repository Closure ................................................................................................................................................ F7.7-15[a]</td>
<td></td>
</tr>
<tr>
<td>7.7.1-16[a]. Expected Annual Dose from 300 Epistemic Uncertainty Vectors, Along with their Quantiles and Expected Dose from Epistemic Uncertainty Vector 247 for the Waste Package Early Failure Modeling Case for 1,000,000 Years after Repository Closure: (a) Linear Time and (b) Log Time ........................................................................................................................................................................ F7.7-16[a]</td>
<td></td>
</tr>
<tr>
<td>7.7.1-17[a]. Annual Dose from Realizations 4921 through 4940 of the Waste Package Early Failure Modeling Case for 1,000,000 Years after Repository Closure........................................................................................................................................................................ F7.7-17[a]</td>
<td></td>
</tr>
<tr>
<td>7.7.1-18[a]. Major Radionuclide Dose Contributors for Realization (a) 4930 and (b) 4940 of the Waste Package Early Failure Modeling Case for 1,000,000 Years after Repository Closure ........................................................................................................................................................................ F7.7-18[a]</td>
<td></td>
</tr>
<tr>
<td>7.7.1-19[a]. Saturated Zone Breakthrough Curves for Epistemic Uncertainty Vector 247 of the Waste Package Early Failure Modeling Case for 1,000,000 Years after Repository Closure ........................................................................................................................................................................ F7.7-19[a]</td>
<td></td>
</tr>
<tr>
<td>7.7.1-20[a]. Concentration of (a) $^{239}$Pu and (b) $^{242}$Pu for Realization 4930 of the Waste Package Early Failure Modeling Case for 1,000,000 Years after Repository Closure ........................................................................................................................................................................ F7.7-20[a]</td>
<td></td>
</tr>
<tr>
<td>7.7.1-21[a]. Expected Annual Dose from 300 Epistemic Uncertainty Vectors, Along with their Quantiles and Expected Dose from Epistemic Uncertainty Vector 228 for the Drip Shield Early Failure Modeling Case for 1,000,000 Years after Repository Closure ........................................................................................................................................................................ F7.7-21[a]</td>
<td></td>
</tr>
<tr>
<td>7.7.1-22[a]. Major Radionuclide Contributors to Mean Annual Dose for the Drip Shield Early Failure Modeling Case for 1,000,000 Years after Repository Closure ........................................................................................................................................................................ F7.7-22[a]</td>
<td></td>
</tr>
<tr>
<td>7.7.1-23[a]. Annual Dose for Ten Aleatory Uncertainty Realizations (Vectors) for the Epistemic Uncertainty Vector 228 of the Drip Shield Early Failure Modeling Case for 1,000,000 Years after Repository Closure ........................................................................................................................................................................ F7.7-23[a]</td>
<td></td>
</tr>
</tbody>
</table>
### FIGURES (Continued)

<table>
<thead>
<tr>
<th>Figure Number</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.7.1-24[a]</td>
<td>(a) Annual Dose along with Major Radionuclide Dose Contributors and (b) Contribution of (^{239}\text{Pu}) and (^{242}\text{Pu}) (Aqueous and Associated Irreversibly with Colloids) for Realization 2278 of the Drip Shield Early Failure Modeling Case for 1,000,000 Years after Repository Closure</td>
</tr>
<tr>
<td>7.7.1-25[a]</td>
<td>EBS Release Rates of (^{99}\text{Tc}) Along with Waste Package Temperatures for the Two Selected Realizations (2273 and 2278) of the Drip Shield Early Failure Modeling Case for 1,000,000 Years after Repository Closure</td>
</tr>
<tr>
<td>7.7.1-26[a]</td>
<td>Flow Rate Incident on the Waste Package Showing the Effects of Drift Wall Condensation and Climate Change for the Two Selected Realizations (2273 and 2278) of the Drip Shield Early Failure Modeling Case for 1,000,000 Years after Repository Closure</td>
</tr>
<tr>
<td>7.7.1-27[a]</td>
<td>Fraction of CSNF and HLW Glass Waste Form Degraded for the Two Selected Realizations (2273 and 2278) of the Drip Shield Early Failure Modeling Case for 1,000,000 Years after Repository Closure</td>
</tr>
<tr>
<td>7.7.1-28[a]</td>
<td>Fraction of EBS Mass Flux Released into Unsaturated Zone Fractures for Selected Radionuclides for Realization 2278 of the Drip Shield Early Failure Modeling Case for 1,000,000 Years after Repository Closure</td>
</tr>
<tr>
<td>7.7.1-29[a]</td>
<td>Cumulative Mass Release of (^{99}\text{Tc}) and (^{242}\text{Pu}) from the EBS, Unsaturated Zone, and Saturated Zone for Realization 2278 of the Drip Shield Early Failure Modeling Case for 1,000,000 Years after Repository Closure</td>
</tr>
<tr>
<td>7.7.1-30[a]</td>
<td>Expected Annual Dose and Epistemic Uncertainty Vector 244 for the Drip Shield Early Failure Modeling Case for 1,000,000 Years after Repository Closure</td>
</tr>
<tr>
<td>7.7.1-31[a]</td>
<td>Ten Aleatory Uncertainty Vectors for the Epistemic Uncertainty Vector 244 of the Drip Shield Early Failure Modeling Case for 1,000,000 Years after Repository Closure</td>
</tr>
<tr>
<td>7.7.1-32[a]</td>
<td>Major Radionuclide Dose Contributors to Annual Dose for Realization 2433 of the Drip Shield Early Failure Modeling Case for 1,000,000 Years after Repository Closure</td>
</tr>
<tr>
<td>7.7.1-33[a]</td>
<td>Seepage Fraction Statistics and Seepage Fraction for Realization 2433 for the Drip Shield Early Failure Modeling Case for 1,000,000 Years after Repository Closure</td>
</tr>
<tr>
<td>7.7.1-34[a]</td>
<td>Seepage Rate Statistics and Seepage Rate for Realization 2433 for the Drip Shield Early Failure Modeling Case for 1,000,000 Years after Repository Closure</td>
</tr>
<tr>
<td>7.7.1-35[a]</td>
<td>Saturated Zone Breakthrough Curves for Plutonium and Neptunium for All Four Saturated Zone Regions for Realization 2433 of the Drip Shield Early Failure Modeling Case for 1,000,000 Years after Repository Closure</td>
</tr>
</tbody>
</table>
FIGURES (Continued)

7.7.1-36[a]. Major Radionuclide Contributors to Mean Annual Dose for the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure

7.7.1-37[a]. Expected Annual Dose from the 300 Epistemic Uncertainty Vectors Along with their Quantiles and Expected Dose from Epistemic Uncertainty Vector 286 for the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure

7.7.1-38[a]. Annual Dose for Realizations 2851 through 2860 (representing Epistemic Uncertainty Vector 286) along with Selected Realization 2855 of the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure

7.7.1-39[a]. Major Radionuclide Dose Contributors to Annual Dose for Realization 2855 of the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure

7.7.1-40[a]. Dissolved Concentrations and Solubility Limits of Neptunium, Plutonium, Uranium, and Radium in the CSNF Waste Form Domain for Percolation Subregion 3 Seeping Environment for Realization 2855 of the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure

7.7.1-41[a]. In-Package pH and $P_{CO_2}$ in the Waste Form Domain for Percolation Subregion 3 Seeping Environment for Realization 2855 of the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure

7.7.1-42[a]. Release Rate of Major Radionuclides from all Waste Packages for Realization 2855 of the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure

7.7.1-43[a]. Advective and Diffusive Release Rates of Major Radionuclides (Dissolved and Reversibly Associated with Colloids) from the CSNF WPs for Realization 2855 of the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure

7.7.1-44[a]. Total Dissolved Concentrations and Solubility Limits of Neptunium, Plutonium, Uranium, and Radium in the Corrosion Products Domain of CSNF WPs Located in Percolation Subregion 3 Seeping Environment for Realization 2855 of the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure

7.7.1-45[a]. Cumulative Releases of: (a) $^{237}$Np, (b) $^{234}$U, (c) $^{242}$Pu (Dissolved and Reversibly Associated with Colloids), and (d) $^{226}$Ra from the EBS, Unsaturated Zone, and Saturated Zone for Realization 2855 of the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure

7.7.1-46[a]. Concentrations of Major Radionuclides (Dissolved and Reversibly Associated with Colloids) at the RMEI Location for Realization 2855 of the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure
FIGURES (Continued)

7.7.1-47[a].  Expected Annual Dose from the 300 Epistemic Uncertainty Vectors along with their Quantiles and Expected Dose from Epistemic Uncertainty Vector 20 for the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure ............................................. F7.7-48[a]

7.7.1-48[a].  Annual Dose from the Ten Aleatory Vectors Associated with the Epistemic Uncertainty Vector 20 for the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure ............................................. F7.7-49[a]

7.7.1-49[a].  Major Radionuclide Dose Contributors to Annual Dose for Realization 191 of the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure ............................................. F7.7-50[a]

7.7.1-50[a].  Climate Status and Water Flux for Realization 191 of the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure ............................................. F7.7-51[a]

7.7.1-51[a].  Solubility and Dissolved Concentrations of Plutonium and Uranium within the CSNF Domain for Realization 191 of the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure ............................................. F7.7-52[a]

7.7.1-52[a].  Expected Annual Dose from the 300 Epistemic Uncertainty Vectors Along With their Quantiles and Expected Dose from Epistemic Uncertainty Vector 155 for the Seismic Ground Motion Modeling Case for 1,000,000 Years after Repository Closure ............................................. F7.7-53[a]

7.7.1-53[a].  Annual Dose from the Thirty Aleatory Vectors (Seismic Event Sequences) Associated with the Epistemic Uncertainty Vector 155 for the Seismic Ground Motion Modeling Case for 1,000,000 Years after Repository Closure ............................................. F7.7-54[a]

7.7.1-54[a].  Annual Dose along with Major Radionuclide Dose Contributors for Realization 4641 of the Seismic Ground Motion Modeling Case for 1,000,000 Years after Repository Closure ............................................. F7.7-55[a]

7.7.1-55[a].  Number of Seismic Events and the Peak Ground Velocities for Realization 4641 of the Seismic Ground Motion Modeling Case for 1,000,000 Years after Repository Closure ............................................. F7.7-56[a]

7.7.1-56[a].  Failure Fraction for the Drip Shield Plate and Framework and the Fraction of the Collapsed Drift Filled with Rubble (Lithophysal Zone) for Realization 4641 of the Seismic Ground Motion Modeling Case for 1,000,000 Years after Repository Closure ............................................. F7.7-57[a]

7.7.1-57[a].  CDSP WP Failure for Each Percolation Subregion for Both Seeping and Non-Seeping Environments for Realization 4641 of the Seismic Ground Motion Modeling Case for 1,000,000 Years after Repository Closure ............................................. F7.7-58[a]

7.7.1-58[a].  CSNF WP Failure for Each Percolation Subregion for Both Seeping and Non-Seeping Environments for Realization 4641 of the Seismic Ground Motion Modeling Case for 1,000,000 Years after Repository Closure ............................................. F7.7-59[a]
FIGURES (Continued)

7.7.1-59[a]. CDSP WP Opening Area after Failure from Cracks and Patches for Percolation Subregion 3 for Realization 4641 of the Seismic Ground Motion Modeling Case for 1,000,000 Years after Repository Closure. .......................................................... F7.7-60[a]

7.7.1-60[a]. CSNF WP Opening Area after Failure from Cracks and Patches for Percolation Subregion 3 for Realization 4641 of the Seismic Ground Motion Modeling Case for 1,000,000 Years after Repository Closure. .......................................................... F7.7-61[a]

7.7.1-61[a]. Average Waste Package Outer Barrier Thicknesses and Waste Package Failure Fractions for Percolation Subregion 3 for Realization 4641 of the Seismic Ground Motion Modeling Case for 1,000,000 Years after Repository Closure. .......................................................... F7.7-62[a]

7.7.1-62[a]. Diffusive Release Rates of: (a) $^{99}$Tc and (b) $^{242}$Pu (Dissolved and Reversibly Associated with Colloids) from CDSP WPs from each Percolation Subregion for Realization 4641 of the Seismic Ground Motion Modeling Case for 1,000,000 Years after Repository Closure. .......................................................... F7.7-63[a]

7.7.1-63[a]. Dissolved Concentration of $^{242}$Pu in the Corrosion Products Domain Compared to the Sorbed Concentration on Corrosion Products for CDSP WPs for Percolation Subregion 3 Seeping Environment for Realization 4641 of the Seismic Ground Motion Modeling Case for 1,000,000 Years after Repository Closure. .......................................................... F7.7-64[a]

7.7.1-64[a]. Diffusive Release Rates of (a) $^{99}$Tc and (b) $^{242}$Pu (Dissolved and Reversibly Associated with Colloids) from CSNF WPs from each Percolation Subregion for Realization 4641 of the Seismic Ground Motion Modeling Case for 1,000,000 Years after Repository Closure. .......................................................... F7.7-65[a]

7.7.1-65[a]. Comparison of $^{242}$Pu Cumulative Mass Released from the Inventory, Mass Sorbed on Corrosion Products, and the Dissolved Concentration in the Corrosion Products Domain for CSNF WPs for Percolation Subregion 3 Seeping Environment for Realization 4641 of the Seismic Ground Motion Modeling Case for 1,000,000 Years after Repository Closure. .......................................................... F7.7-66[a]

7.7.1-66[a]. pH and Ionic Strength Profiles in the Corrosion Products Domain for CSNF WPs for Percolation Subregion 3 Seeping Environment for Realization 4641 of the Seismic Ground Motion Modeling Case for 1,000,000 Years after Repository Closure. .......................................................... F7.7-67[a]

7.7.1-67[a]. Concentration of $^{242}$Pu in the CSNF and CDSP WPs (Corrosion Products Domain) for Percolation Subregion 3 Seeping Environment for Realization 4641 of the Seismic Ground Motion Modeling Case for 1,000,000 Years after Repository Closure. .......................................................... F7.7-68[a]

7.7.1-68[a]. Concentration of Various Colloids in the CSNF and CDSP WPs (Corrosion Products Domain) for Percolation Subregion 3 Seeping Environment for Realization 4641 of the Seismic Ground Motion Modeling Case for 1,000,000 Years after Repository Closure. .......................................................... F7.7-69[a]

7.7.1-69[a]. EBS Release Rates from CSNF and CDSP WPs (All Percolation Subregions) for Realization 4641 of the Seismic Ground Motion Modeling Case for 1,000,000 Years after Repository Closure. .......................................................... F7.7-70[a]
### FIGURES (Continued)

<table>
<thead>
<tr>
<th>Page</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>F7.7-71[a]</td>
<td>Fraction of $^{242}$Pu Mass Going to Unsaturated Zone Fractures at the Repository Horizon for Realization 4641 of the Seismic Ground Motion Modeling Case for 1,000,000 Years after Repository Closure</td>
</tr>
<tr>
<td>F7.7-72[a]</td>
<td>Cumulative Mass Release of $^{99}$Tc and $^{242}$Pu from the EBS, Unsaturated Zone, and Saturated Zone for Realization 4641 of the Seismic Ground Motion Modeling Case for 1,000,000 Years after Repository Closure</td>
</tr>
<tr>
<td>F7.7-73[a]</td>
<td>Comparison of Saturated Zone Breakthrough Curves for $^{99}$Tc and $^{242}$Pu for All Four Saturated Zone Source Regions for Realization 4641 of the Seismic Ground Motion Modeling Case for 1,000,000 Years after Repository Closure</td>
</tr>
<tr>
<td>F7.7-74[a]</td>
<td>Saturated Zone Release at the Location of the RMEI of $^{99}$Tc and $^{242}$Pu for Realization 4641 of the Seismic Ground Motion Modeling Case for 1,000,000 Years after Repository Closure</td>
</tr>
<tr>
<td>F7.7-75[a]</td>
<td>Expected Annual Dose from 300 Epistemic Uncertainty Vectors, Along with their Quantiles for the Nominal Modeling Case for 1,000,000 Years after Repository Closure in (a) Linear Time and (b) Log Time</td>
</tr>
<tr>
<td>F7.7-76[a]</td>
<td>Contribution of Individual Radionuclides to Mean Annual Dose for the Nominal Modeling Case for 1,000,000 Years after Repository Closure</td>
</tr>
<tr>
<td>F7.7-77[a]</td>
<td>Expected Annual Dose from 300 Epistemic Uncertainty Vectors, Along with their Quantiles and Expected Dose from Epistemic Uncertainty Vector 286 for the Nominal Modeling Case for 1,000,000 Years after Repository Closure</td>
</tr>
<tr>
<td>F7.7-78[a]</td>
<td>Contribution of Individual Radionuclides to Expected Annual Dose for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure</td>
</tr>
<tr>
<td>F7.7-79[a]</td>
<td>Expected Number of (a) CDSP WP Failures and (b) CSNF WP Failures by Percolation Subregion for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure</td>
</tr>
<tr>
<td>F7.7-80[a]</td>
<td>Average Failure Area for (a) CDSP WPs and (b) CSNF WPs by Percolation Subregion for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure</td>
</tr>
<tr>
<td>F7.7-81[a]</td>
<td>Release Rates of $^{129}$I from the Waste Form, Waste Package, Invert, Unsaturated Zone, and Saturated Zone for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure</td>
</tr>
<tr>
<td>F7.7-82[a]</td>
<td>Release Rates of $^{79}$Se from the Waste Form, Waste Package, Invert, Unsaturated Zone, and Saturated Zone for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure</td>
</tr>
</tbody>
</table>
### FIGURES (Continued)

<table>
<thead>
<tr>
<th>FIGURE</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.7.1-82[a].</td>
<td>Release Rates of $^{135}$Cs from the Waste Form, Waste Package, Invert, Unsaturated Zone, and Saturated Zone for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure</td>
</tr>
<tr>
<td>7.7.1-83[a].</td>
<td>Release Rates of $^{242}$Pu (Dissolved and Reversibly Associated with Colloids) from the Waste Form, Waste Package, Invert, Unsaturated Zone, and Saturated Zone for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure</td>
</tr>
<tr>
<td>7.7.1-84[a].</td>
<td>Diffusive and Advective Release Rates of $^{129}$I from the CDSP and CSNF Waste Packages for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure</td>
</tr>
<tr>
<td>7.7.1-85[a].</td>
<td>Diffusive and Advective Release Rates of $^{242}$Pu (Dissolved and Reversibly Associated with Colloids) from the CDSP and CSNF Waste Packages for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure</td>
</tr>
<tr>
<td>7.7.1-86[a].</td>
<td>Fraction of $^{129}$I Mass Going to Unsaturated Zone Fractures at the Repository Horizon for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure</td>
</tr>
<tr>
<td>7.7.1-87[a].</td>
<td>Fraction of $^{242}$Pu Mass Going to Unsaturated Zone Fractures at the Repository Horizon for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure</td>
</tr>
<tr>
<td>7.7.1-88[a].</td>
<td>Expected Annual Dose for Aqueous $^{242}$Pu and Slow and Fast Fractions of Irreversibly Sorbed Colloidal $^{242}$Pu for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure</td>
</tr>
<tr>
<td>7.7.1-89[a].</td>
<td>Expected Annual Dose from the 300 Epistemic Uncertainty Vectors along with their Quantiles and Expected Dose from Epistemic Uncertainty Vector 85 for the Nominal Modeling Case for 1,000,000 Years after Repository Closure</td>
</tr>
<tr>
<td>7.7.1-90[a].</td>
<td>Contribution of Individual Radionuclides to Expected Annual Dose of Realization 85 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure</td>
</tr>
<tr>
<td>7.7.1-91[a].</td>
<td>(a) Release Rates of $^{242}$Pu (Dissolved and Reversibly Associated with Colloids) from the Waste Form, Waste Package, Invert, Unsaturated Zone, and Saturated Zone, and (b) CSNF WP Failure History for Realization 85 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure</td>
</tr>
<tr>
<td>7.7.1-92[a].</td>
<td>Expected Annual Dose from the 300 Epistemic Uncertainty Vectors along with their Quantiles and Expected Dose from Epistemic Uncertainty Vector 277 for the Human Intrusion Modeling Case for 1,000,000 Years after Repository Closure</td>
</tr>
<tr>
<td>7.7.1-93[a].</td>
<td>Annual Dose from the Thirty Aleatory Vectors Associated with the Epistemic Uncertainty Vector 277 for the Human Intrusion Modeling Case for 1,000,000 Years after Repository Closure</td>
</tr>
</tbody>
</table>
7.7.1-94[a]. Annual Dose along with Major Radionuclide Dose Contributors for Realization 8309 of the Human Intrusion Modeling Case for 1,000,000 Years after Repository Closure............................................. F7.7-95[a]

7.7.1-95[a]. Cumulative Release of $^{99}$Tc and $^{242}$Pu from the Inventory for Percolation Subregion 4 for Realization 8309 of the Human Intrusion Modeling Case for 1,000,000 Years after Repository Closure............................. F7.7-96[a]

7.7.1-96[a]. Advective and Diffusive Release Rates of $^{99}$Tc from Waste Form and Corrosion Products Domain for failed CSNF WPs for Realization 8309 of the Human Intrusion Modeling Case for 1,000,000 Years after Repository Closure .................................................. F7.7-97[a]

7.7.1-97[a]. Advective and Diffusive Release Rates of $^{242}$Pu (Aqueous) from Waste Form and Corrosion Products Domain and $^{242}$Pu (Irreversibly Sorbed on Iron Oxyhydroxide Colloids) from Corrosion Products Domain for failed CSNF WPs for Realization 8309 of the Human Intrusion Modeling Case for 1,000,000 Years after Repository Closure ..................................................................................................... F7.7-98[a]

7.7.1-98[a]. Dissolved Concentration of $^{242}$Pu in the Waste Form and Corrosion Products Domain, the Plutonium Solubility in Respective Domains, and Concentration of $^{242}$Pu Irreversibly Sorbed on Iron Oxyhydroxide Colloids for Realization 8309 of the Human Intrusion Modeling Case for 1,000,000 Years after Repository Closure............................................. F7.7-99[a]

7.7.1-99[a]. Comparison of $^{99}$Tc Release from Waste Package, Unsaturated Zone Borehole, and Saturated Zone for Realization 8309 of the Human Intrusion Modeling Case for 1,000,000 Years after Repository Closure .................................................................................................. F7.7-100[a]

7.7.1-100[a]. Comparison of $^{242}$Pu (Dissolved and Reversibly Associated with Colloids) Release from Waste Package, Unsaturated Zone Borehole, and Saturated Zone for Realization 8309 of the Human Intrusion Modeling Case for 1,000,000 Years after Repository Closure........................................................................ F7.7-101[a]

7.7.1-101[a]. Cumulative Release Comparison of $^{99}$Tc, $^{242}$Pu (Aqueous), and $^{242}$Pu (Irreversibly Sorbed on Colloids) from Waste Package, Unsaturated Zone Borehole, and Saturated Zone for Realization 8309 of the Human Intrusion Modeling Case for 1,000,000 Years after Repository Closure........................................................................ F7.7-102[a]

7.7.1-102[a]. Saturated Zone Release Rates to the Biosphere for $^{99}$Tc, $^{242}$Pu (Aqueous), $^{242}$Pu (Irreversibly Sorbed on Colloids that Travel Slowly due to Retardation), and $^{242}$Pu (Irreversibly Sorbed on Colloids that Travel Fast due to no Retardation) for Realization 8309 of the Human Intrusion Modeling Case for 1,000,000 Years after Repository Closure........................................................................ F7.7-103[a]

7.7.1-103[a]. Expected Annual Dose from the 300 Epistemic Uncertainty Vectors along with their Quantiles and Expected Dose from Epistemic Uncertainty Vector 181 for the Human Intrusion Modeling Case for 1,000,000 Years after Repository Closure ........................................................................ F7.7-104[a]
7.7.1-104[a]. Annual Dose from the Thirty Aleatory Vectors Associated with the Epistemic Uncertainty Vector 181 for the Human Intrusion Modeling Case for 1,000,000 Years after Repository Closure.................. F7.7-105[a]

7.7.1-105[a]. Annual Dose along with Major Radionuclide Dose Contributors for Realization 5415 of the Human Intrusion Modeling Case for 1,000,000 Years after Repository Closure.............................................................. F7.7-106[a]

7.7.1-106[a]. Dissolved Concentration of $^{242}$Pu in the Waste Form and Corrosion Products Domains, the Plutonium Solubility in Respective Domains, and Concentration of $^{242}$Pu Irreversibly Sorbed on Iron Oxyhydroxide Colloids for Realization 5415 of the Human Intrusion Modeling Case for 1,000,000 Years after Repository Closure............... F7.7-107[a]

7.7.1-107[a]. Expected Annual Dose from the 300 Epistemic Uncertainty Vectors along with their Quantiles and Expected Dose from Epistemic Uncertainty Vector 155 for the Seismic Ground Motion Modeling Case for 10,000 Years after Repository Closure................................. F7.7-108[a]

7.7.1-108[a]. Annual Dose from the Thirty Aleatory Vectors Associated with the Epistemic Uncertainty Vector 155 for the Seismic Ground Motion Modeling Case for 10,000 Years after Repository Closure................................. F7.7-109[a]

7.7.1-109[a]. Annual Dose along with Major Radionuclide Dose Contributors for Realization 4628 of the Seismic Ground Motion Modeling Case for 10,000 Years after Repository Closure................................. F7.7-110[a]

7.7.1-110[a]. CDSP WP Failure History in all Five Percolation Subregions for Both Seeping and Non-Seeping Environments for Realization 4628 of the Seismic Ground Motion Modeling Case for 10,000 Years after Repository Closure......................................................... F7.7-111[a]

7.7.1-111[a]. Diffusive Release Rates of $^{99}$Tc from CDSP WPs from each Percolation Subregion for Realization 4628 of the Seismic Ground Motion Modeling Case for 10,000 Years after Repository Closure...... F7.7-112[a]

7.7.1-112[a]. Diffusive Release Rates of $^{79}$Se from CDSP WPs from each Percolation Subregion for Realization 4628 of the Seismic Ground Motion Modeling Case for 10,000 Years after Repository Closure...... F7.7-113[a]

7.7.1-113[a]. Mass Flux of $^{99}$Tc from the EBS for Percolation Subregion 3 (Seeping and Non-Seeping Environments) for Realization 4628 of the Seismic Ground Motion Modeling Case for 10,000 Years after Repository Closure.............................................................................. F7.7-114[a]

7.7.1-114[a]. Comparison of Dissolved Concentration of $^{99}$Tc from the Various EBS Transport Domains and Fraction of HLW Degraded for CDSP Percolation Subregion 3, Non-Seeping Environment for Realization 4628 of the Seismic Ground Motion Modeling Case for 10,000 Years after Repository Closure......................................................... F7.7-115[a]

7.7.1-115[a]. Comparison of Diffusive Releases of $^{99}$Tc from the Various EBS Transport Domains for CDSP Percolation Subregion 3, Non-Seeping Environment for Realization 4628 of the Seismic Ground Motion Modeling Case for 10,000 Years after Repository Closure................................. F7.7-116[a]
### FIGURES (Continued)

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.7.1-116[a]</td>
<td>Fraction of $^{99}$Tc Mass Going to Unsaturated Zone Fractures as Compared to the Unsaturated Zone Matrix at the Repository Horizon for Realization 4628 of the Seismic Ground Motion Modeling Case for 10,000 Years after Repository Closure</td>
<td>F7.7-117[a]</td>
</tr>
<tr>
<td>7.7.1-117[a]</td>
<td>Fraction of $^{79}$Se Mass Going to Unsaturated Zone Fractures as Compared to the Unsaturated Zone Matrix at the Repository Horizon for Realization 4628 of the Seismic Ground Motion Modeling Case for 10,000 Years after Repository Closure</td>
<td>F7.7-118[a]</td>
</tr>
<tr>
<td>7.7.1-118[a]</td>
<td>Cumulative Release of $^{99}$Tc from Various Model Domains for Realization 4628 of the Seismic Ground Motion Modeling Case for 10,000 Years after Repository Closure</td>
<td>F7.7-119[a]</td>
</tr>
<tr>
<td>7.7.1-119[a]</td>
<td>Cumulative Release of $^{79}$Se from Various Model Domains for Realization 4628 of the Seismic Ground Motion Modeling Case for 10,000 Years after Repository Closure</td>
<td>F7.7-120[a]</td>
</tr>
<tr>
<td>7.7.1-120[a]</td>
<td>Comparison of Saturated Zone Breakthrough Curves for $^{99}$Tc and $^{79}$Se for All Four Saturated Zone Regions for Realization 4628 of the Seismic Ground Motion Modeling Case for 10,000 Years after Repository Closure</td>
<td>F7.7-121[a]</td>
</tr>
<tr>
<td>7.7.1-121[a]</td>
<td>Saturated Zone Release to the Biosphere for $^{99}$Tc and $^{79}$Se for Realization 4628 of the Seismic Ground Motion Modeling Case for 10,000 Years after Repository Closure</td>
<td>F7.7-122[a]</td>
</tr>
<tr>
<td>7.7.2-3[a]</td>
<td>Time-Slice Comparison of the Simplified TSPA Analysis Results against the TSPA-LA Model Results for the Waste Package Early Failure Modeling Case</td>
<td>F7.7-123[a]</td>
</tr>
<tr>
<td>7.7.2-6[a]</td>
<td>Time-Slice Comparison of the Simplified TSPA Analysis Results against the TSPA-LA Model Results for the Nominal Modeling Case</td>
<td>F7.7-124[a]</td>
</tr>
<tr>
<td>7.7.2-9[a]</td>
<td>Time-Slice Comparison of the Simplified TSPA Analysis Results against the TSPA-LA Model Results for the Seismic Ground Motion Modeling Case</td>
<td>F7.7-125[a]</td>
</tr>
<tr>
<td>7.7.2-12[a]</td>
<td>Time-Slice Comparison of the Simplified TSPA Analysis Results against the TSPA-LA Model Results for the Igneous Intrusion Modeling Case</td>
<td>F7.7-126[a]</td>
</tr>
<tr>
<td>7.7.3-2[a]</td>
<td>TSPA-LA Nominal Scenario Class Mean Failure Curves for the Drip Shield and Waste Package</td>
<td>F7.7-127[a]</td>
</tr>
<tr>
<td>7.7.3-3[a]</td>
<td>TSPA-LA Mean Annual Dose for Major Radionuclides for the Combined Early Failure and Nominal Scenario Classes</td>
<td>F7.7-128[a]</td>
</tr>
<tr>
<td>7.7.4-7[a]</td>
<td>Comparison of Total Mean Annual Dose for TSPA-LA Model Version 5.000, Version 5.005, and the Performance Margin Analysis for: (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure</td>
<td>F7.7-129[a]</td>
</tr>
</tbody>
</table>
TABLES

7.1-1[a]. TSPA-LA Model v5.005 Validation Analyses .......................................................7-5[a]

7.3.1-1[a]. Uncertainty Distribution Changes for TSPA-LA Model v5.005 .........................7-29[a]

7.3.3-2[a]. Revised Timestep Schemes used in Temporal Stability Analysis ....................7-37[a]
INTENTIONALLY LEFT BLANK
7[a]. MODEL VALIDATION AND CONFIDENCE BUILDING

One distinguishing characteristic of validating and building confidence in the Total System Performance Assessment for the License Application (TSPA-LA) Model is the iterative nature of the process. The results presented in this addendum were generated with an updated version of the TSPA-LA Model, v5.005, and address issues that were identified during detailed post-development analysis, checking, and review of the TSPA-LA Model v5.000 results described in the parent document. The issues were primarily related to inaccuracies in model implementation and identification of unintended conservatisms as documented in Appendix P of the parent document. Changes were made to the TSPA-LA Model to address the issues presented in Appendix P of the parent document and to address unintended conservatisms in the TSPA-LA Model, as indicated in Appendix P[a] of this addendum. Appendix P[a] of this addendum includes updated tables that summarize the issues that have been addressed in the TSPA-LA Model v5.005.

Appendix P of the parent document describes the identified issues and errors, and assesses their anticipated impacts. The overall impacts on mean annual dose were projected to be "negligible" or "small" with one issue assessed as "significant" in a specified timeframe. These projected impacts were based on the understanding of the TSPA-LA Model v5.000 results during post-development analysis and review activities. As described below and listed in Tables P-6[a] and P-7[a], the projected impacts were confirmed in the TSPA-LA Model v5.005 results, indicating that the v5.000 results were well understood. The validation portion of the model documentation in the parent document was judged adequate for the intended purpose of TSPA-LA Model performance analyses in evaluating the postclosure performance of the repository and its compliance with U.S. Nuclear Regulatory Commission Proposed Rule 10 CFR 63.113 [DIRS 180319] and the performance measures defined in proposed 10 CFR 63.303 [DIRS 178394] for the individual protection standard after permanent closure in proposed 10 CFR 63.311a(1) and (2) [DIRS 178394], the individual protection standard for human intrusion in 10 CFR 63.321(a)(1) and (2) [DIRS 178394], and the separate standards for protection of groundwater in 10 CFR 63.331 [DIRS 180319], Table 1. The next iteration of the evaluation is the subject of this addendum. Confidence has been enhanced because the process has proceeded to identify, describe, and fix issues and errors during development of a thorough understanding of the results. However, it is still necessary to re-assess the adequacy of the validation portion of the model documentation of the parent document and update activities if necessary. Thus, in preparing this addendum, each validation activity for TSPA-LA Model v5.000 was reviewed to determine which activities were affected by changes made between TSPA-LA Model v5.000 and v5.005. Where validation activities could potentially be affected by model changes, these validation activities were repeated using v5.005 to verify that model changes did not adversely affect the overall validation of the TSPA-LA Model. Additional verification and validation results beyond those presented in the parent document are also provided to further enhance confidence in the TSPA-LA Model. The following validation activities were conducted for TSPA-LA Model v5.005 and are documented in this addendum:

- Computer code and input re-verification (Section 7.2[a]) including:
  - Verification testing for the Human Intrusion Submodel inadvertently omitted from the parent document (Section 7.2.4.1.12[a])
• Summary of an assessment of the range of validity for all TSPA-LA Model submodels inadvertently omitted from the parent document (Section 7.2.6[a])

• Demonstration of Model Stability (Section 7.3[a])
  – Comparison between TSPA-LA Model v5.000 and v5.005 expected dose results (Section 7.3.1[a])
  – Reevaluation of the statistical stability of TSPA-LA Model v5.005 results (Section 7.3.1[a])
  – Confirmation of numerical accuracy of expected dose results for the Seismic Fault Displacement Modeling Case (Section 7.3.2.7[a])
  – Reevaluation of the temporal stability testing for the Human Intrusion Modeling Case as the result of a change to the timestep size for this modeling case (Section 7.3.3.6[a])
  – Evaluation of the temporal stability of the Nominal Modeling Case (Section 7.3.3.7[a])

• Surrogate Waste Form Validation (Section 7.5[a])
  – Reevaluation of the adequacy of using commercial spent nuclear fuel (CSNF) as a surrogate for naval spent nuclear fuel (NSNF) using TSPA-LA Model v5.005 (Section 7.5.3[a])

• Reevaluation of the corroboration of the TSPA-LA Model results documented in the parent document with auxiliary analyses (Section 7.7[a]), including:
  – Updated analyses of single realizations for the Early Failure Scenario Class, the Igneous Intrusion Modeling Case, and the Seismic Ground Motion (GM) Modeling Case for 1,000,000 years, including additional analyses of outlier realizations (Section 7.7.1[a])
  – Additional analyses of single realizations including: (1) the Nominal Scenario Class (Section 7.7.1.5[a]), (2) a Seismic GM Modeling Case for 10,000 years (Section 7.7.1.7[a]), and (3) the Human Intrusion Scenario (Section 7.7.1.6[a])
  – Updated evaluation with a Simplified TSPA Analysis (Section 7.7.2[a])
  – Updated evaluation with the Electric Power Research Institute (EPRI) Analysis (Section 7.7.3[a])
  – Reevaluation of a comparison of results from the Performance Margin Analysis (PMA) (Section 7.7.4[a]).
These additional verification and validation activities are presented to further enhance confidence in the TSPA-LA Model. Table 7.1-1[a] includes the verification and validation analyses presented in this addendum as well as those documented in the parent document. The analyses presented in this addendum confirm that TSPA-LA Model v5.005 is within the range of validation previously documented in the parent document.

**7.1[a] MODEL VALIDATION STRATEGY**

Table 7.1-1 of the parent document has been revised to include the verification and validation analyses presented in this addendum. Table 7.1-1[a] includes cross-references for the model validation analyses documented in Section 7 of the parent document and Section 7[a] of this addendum.
### Table 7.1-1[a]. TSPA-LA Model v5.005 Validation Analyses

<table>
<thead>
<tr>
<th>Activity Category/Subcategory</th>
<th>Purpose</th>
<th>Activity Description</th>
<th>Document Section</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>During–Development Validation Activities</strong> (Technical Work Plan Validation (SNL 2008 [DIRS 184920], Section 2.3.5.1))</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Computer Code and Input Verification</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model Testing and Verification</td>
<td>Testing of software that is the basis for the TSPA-LA Model.</td>
<td>Verify GoldSim software, version 9.60.100 (STN: 10344-9.60-01 [DIRS 181903]) and 9.60.300 (STN: 10344-9.60-03 [DIRS 184387]).</td>
<td>7.2.1 and 7.2.1[a]</td>
</tr>
<tr>
<td></td>
<td>Checking to determine whether the correct input parameters are used.</td>
<td>Verify input parameters.</td>
<td>7.2.3 and 7.2.3[a]</td>
</tr>
<tr>
<td></td>
<td>Test cases to determine whether the model is working correctly, saving appropriate results, interfacing with DLLs, feeding the correct information among model components, and not exceeding the applicable range of model components.</td>
<td>Includes verification of DLLs, submodels, model components, and coupling among submodels and model components; and comparison with other models (e.g., stand-alone models from analysis model reports). In addition, the verification of coupling among submodels and model components includes subsystem analyses of annual release across model interfaces, drift-wall condensation, and localized corrosion initiation.</td>
<td>7.2.2, 7.2.4, 7.2.4[a], 7.2.5, 7.2.6[a]; Tables 7.2-1 and 7.2-2</td>
</tr>
<tr>
<td><strong>Model Stability Testing</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Statistical Stability of Mean Annual Dose</td>
<td>Determine confidence interval around total mean annual dose and mean annual dose for each modeling case using three replicates.</td>
<td>TSPA-LA Model v5.000: Generate total mean annual dose and mean annual dose for each modeling case using three replicates with different random seeds. Determine a confidence interval around the estimate of the overall mean with a t-test. TSPA-LA Model v5.005: Determine stability by comparison with results from TSPA-LA Model v5.000. Determine a confidence interval around the estimate of the overall mean with a bootstrap procedure.</td>
<td>7.3.1, 7.3.1[a]</td>
</tr>
<tr>
<td>Numerical Accuracy of Expected Annual Dose Calculation – Igneous Scenario Class</td>
<td>Demonstrate accuracy of calculation of expected annual dose for the modeling cases of the Igneous Scenario Class.</td>
<td>For the Igneous Intrusion Modeling Case, demonstrate accuracy of the quadrature integration technique by increasing the discretization used in the integral. Increase the number of specified event times from 10 to 50. Calculate expected annual dose for five epistemic realizations for both 10,000 and 1,000,000 years. For the Volcanic Eruption Modeling Case for 10,000 years, demonstrate accuracy of the combined Monte Carlo and quadrature integration techniques by increasing the sample size used in the Monte Carlo integration and the discretization used in the quadrature integration. Calculate expected annual dose for 10,000 years for five epistemic realizations, increasing the aleatory LHS sample size from 40 to 120, and the number of specified event times from 10 to 20. Conclusions for 10,000 years apply to the 1,000,000 year calculations.</td>
<td>7.3.2</td>
</tr>
</tbody>
</table>
### Table 7.1-1[a]. TSPA-LA Model v5.005 Validation Analyses (Continued)

<table>
<thead>
<tr>
<th>Activity Category/Subcategory</th>
<th>Purpose</th>
<th>Activity Description</th>
<th>Document Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>Numerical Accuracy of Expected Annual Dose Calculation – Seismic Scenario Class</td>
<td>Demonstrate accuracy of calculation of expected annual dose for the modeling cases of the Seismic Scenario Class.</td>
<td>For the Seismic GM Modeling Case for 1,000,000 years, demonstrate the accuracy of the Monte Carlo integration technique by means of increased sample size. Repeat Replicate 1 (300 epistemic realizations) with a different aleatory seed to generate a second set of 9,000 dose histories (30 independent aleatory samples for each epistemic realization). Pool the two sets of 9,000 dose histories and generate expected annual dose based on the pooled set of 60 independent aleatory samples per epistemic realization, and compare to expected annual dose for the base case of 30 independent aleatory samples per epistemic realization. For the Seismic GM Modeling Case for 10,000 years, demonstrate accuracy of the quadrature integration technique by increasing the discretization used in each integral. Increase the number of specified event times from 6 to 12 and the number of specified damage levels from 5 to 8. Calculate expected annual dose for 5 epistemic realizations. For the Seismic FD Modeling Case, demonstrate accuracy of the quadrature integration technique by increasing the discretization used in each integral. Increase the number of specified event times from 6 to 12 and the number of specified damaged areas from 3 to 6. Calculate expected annual dose for 5 epistemic realizations for both 10,000 and 1,000,000 years.</td>
<td>7.3.2 and 7.3.2[a]</td>
</tr>
<tr>
<td>Justification of Simplifications for the Seismic GM Modeling Case for 10,000 Years</td>
<td>For the Seismic GM Modeling Case for 10,000 years, demonstrate that simplifications of the Seismic Consequences Abstraction used in the calculation of expected annual dose are reasonable.</td>
<td>Estimate the effect on mean annual dose of drip shield plate rupture and of framework failure. Estimate the effect on mean annual dose of accounting for rockfall effects on temperature and seepage entering the drift. Estimate the contribution to mean annual dose from WP rupture and puncture. Estimate the contribution to mean annual dose from damage to CSNF WPs.</td>
<td>7.3.2</td>
</tr>
<tr>
<td>Temporal Stability</td>
<td>Demonstrate stability of expected annual dose for temporal discretization in GoldSim.</td>
<td>Comparison of expected annual dose histories for five epistemic vectors for the following modeling cases: Waste Package EF; Seismic GM (10,000 years); Igneous Intrusion (10,000 and 1,000,000 years); and Drip Shield EF (10,000 years). Compare expected annual dose histories for different temporal discretizations. Assess the temporal stability for the Nominal Modeling Case (1,000,000 years). Assess the temporal stability for the Human Intrusion Modeling Case.</td>
<td>7.3.3 and 7.3.3[a]; Table 7.3.3-2[a]</td>
</tr>
</tbody>
</table>
Table 7.1-1[a]. TSPA-LA Model v5.005 Validation Analyses (Continued)

<table>
<thead>
<tr>
<th>Activity Category/Subcategory</th>
<th>Purpose</th>
<th>Activity Description</th>
<th>Document Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spatial Discretization</td>
<td>Evaluate the impact due to the spatial discretizations inherited by the TSPA-LA Model from the supporting natural and engineered-barrier process models.</td>
<td>Evaluate the appropriateness of use of the inherited spatial discretization schemes of the process model abstractions that feed the TSPA-LA Model. These abstractions include the process models: Mountain-Scale UZ Flow, EBS TH Environment, UZ Transport, and SZ Flow and Transport abstractions.</td>
<td>7.3.4.1</td>
</tr>
<tr>
<td></td>
<td>Evaluate the impact due to the spatial discretizations created within the TSPA-LA Model.</td>
<td>Describe the spatial discretization of the repository on the basis of percolation subregions and the binning of the percolation subregions by quantiles (0.0 to 0.05, 0.05 to 0.3, 0.3 to 0.7, 0.7 to 0.95, and 0.95 to 1.0).</td>
<td>7.3.4.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Demonstrate the appropriateness and validity of using the representative TH histories as inputs to the EBS Thermal-Hydrologic Environments Submodel of the TSPA-LA Model, as opposed to using the comprehensive data set available from the MSTHM.</td>
<td>7.3.4.3</td>
</tr>
<tr>
<td>Stability of UZ Transport Modeling for the Igneous Intrusion Modeling Case</td>
<td>Evaluate the stability of results in reference to the maximum number of particles allowed per species for the Igneous Intrusion Modeling Case for 10,000 years.</td>
<td>Analyze the differences in UZ releases of $^{99}$Tc, $^{233}$U, $^{234}$U, $^{237}$Np, and $^{239}$Pu, and in cumulative dose for three cases (500,000; 750,000; and 900,000 particles).</td>
<td>7.3.5</td>
</tr>
<tr>
<td>Stability of UZ Transport Modeling for the Seismic GM Modeling Case</td>
<td>Evaluate the stability of results in reference to the maximum number of particles allowed per species for the Seismic GM Modeling Case for 10,000 years.</td>
<td>Analyze the differences in UZ releases of $^{99}$Tc, $^{233}$U, $^{234}$U, $^{237}$Np, and $^{239}$Pu and in cumulative dose for three cases (500,000; 750,000; and 900,000 particles).</td>
<td>7.3.5</td>
</tr>
<tr>
<td>Stability of UZ Transport Modeling for the Drip Shield EF Modeling Case</td>
<td>Evaluate the stability of results in reference to the maximum number of particles allowed per species for the Drip Shield EF Modeling Case for 1,000,000 years.</td>
<td>Analyze the differences in UZ releases of $^{99}$Tc, $^{233}$U, $^{234}$U, $^{237}$Np, and $^{239}$Pu, and in cumulative dose for three cases (500,000; 750,000; and 900,000 particles).</td>
<td>7.3.5</td>
</tr>
</tbody>
</table>

Uncertainty Characterization Reviews

<table>
<thead>
<tr>
<th>Activity Category/Subcategory</th>
<th>Purpose</th>
<th>Activity Description</th>
<th>Document Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ranking of Scenario Classes</td>
<td>Prioritize scenario classes of higher significance to dose.</td>
<td>Develop a risk-based ranking of TSPA-LA scenario classes and modeling cases in order to focus the uncertainty characterization reviews of the most important component model abstractions.</td>
<td>7.4.2</td>
</tr>
<tr>
<td>Key Uncertain Parameters</td>
<td>Identify the key uncertain parameters that are important to dose.</td>
<td>Select the key uncertain parameters that are important to dose in the Seismic, Igneous, and Nominal Modeling Cases for characterization review based on both importance rankings from past TSPA scoping studies and recommendations provided by model abstraction developers and experienced TSPA analysts.</td>
<td>7.4.3</td>
</tr>
<tr>
<td>Activity Category/Subcategory</td>
<td>Purpose</td>
<td>Activity Description</td>
<td>Document Section</td>
</tr>
<tr>
<td>--------------------------------</td>
<td>---------</td>
<td>---------------------</td>
<td>------------------</td>
</tr>
<tr>
<td>Uncertainty-Characterization Review Findings and their Implementation</td>
<td>Review uncertainty characterization and address findings.</td>
<td>Perform uncertainty characterization of the selected key parameters impacting dose for the Seismic, Igneous, and Nominal Modeling Cases and implement corrective actions for observed deficiencies.</td>
<td>7.4.4</td>
</tr>
<tr>
<td>Surrogate Waste Form Validation</td>
<td>Spent Fuel Categories</td>
<td>Comparison of naval surrogate fuel to naval fuel (Category 1).</td>
<td>Perform probabilistic runs to compare the naval surrogate (Zircaloy-clad commercial fuel) with naval fuel for Nominal, Igneous Intrusion, and Volcanic Eruption Modeling Cases.</td>
</tr>
<tr>
<td></td>
<td>Comparison of the DOE surrogate fuel to each DOE spent fuel category (Category 2 through Category 11).</td>
<td>Perform probabilistic run using Drip Shield EF Modeling Case to compare the DOE surrogate with plutonium/uranium alloy spent fuel (Category 2), plutonium/uranium-carbide spent fuel (Category 3), mixed-oxide spent fuel (Category 4), uranium/thorium-carbide spent fuel (Category 5), uranium/thorium-oxide spent fuel (Category 6), uranium-metal spent fuel (Category 7), uranium-oxide spent fuel (Category 8), aluminum-based spent fuel (Category 9), miscellaneous spent fuel (Category 10) for two inventories, and uranium-zirconium hydride spent fuel (Category 11).</td>
<td>7.5.4</td>
</tr>
<tr>
<td>Selected Sensitivity Analyses</td>
<td>Justification of the DOE surrogate dissolution model.</td>
<td>Perform probabilistic comparison of fuel degradation models for Category 2 through Category 11 and air alteration rates for Category 5 and Category 7.</td>
<td>7.5.5</td>
</tr>
<tr>
<td></td>
<td>Justification of the DOE surrogate dissolution model.</td>
<td>Perform comparison of uranium-metal dissolution model, uranium-metal dissolution model with air alteration, and instantaneous dissolution (Category 7). Perform similar comparison for the uranium/thorium-carbide dissolution model (Category 5).</td>
<td>7.5.5</td>
</tr>
<tr>
<td></td>
<td>Effects of fuel surface area and free inventory and uncertainty of radionuclide inventory.</td>
<td>Perform probabilistic comparison of uranium-metal nominal surface area with bounding surface area and free inventory and comparison of nominal inventory with the bounding inventory (Category 7).</td>
<td>7.5.5</td>
</tr>
<tr>
<td></td>
<td>Uncertainty in number of WPs.</td>
<td>Perform probabilistic comparison of aluminum-based spent fuel for nominal and bounding number of WPs (Category 9).</td>
<td>7.5.5</td>
</tr>
<tr>
<td></td>
<td>Comparison of radionuclides that contribute to annual dose from surrogate DOE spent fuel, HLW, uranium-metal spent fuel (Category 7), uranium/thorium-carbide spent fuel (Category 5), and uranium/thorium-oxide spent fuel (Category 6).</td>
<td>Analyze plots of key radionuclides that contribute to total annual dose for the DOE surrogate spent fuel only, HLW only, Category 7 only, Category 5 only, and Category 6 only.</td>
<td>7.5.6</td>
</tr>
</tbody>
</table>
Table 7.1-1[a]. TSPA-LA Model v5.005 Validation Analyses (Continued)

<table>
<thead>
<tr>
<th>Activity Category/Subcategory</th>
<th>Purpose</th>
<th>Activity Description</th>
<th>Document Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corroboration of Abstraction Results with Underlying Process Models</td>
<td>Evaluate consistency of the abstraction results with the underlying validated key natural system environment models.</td>
<td>Perform quantitative and qualitative evaluation of how well the direct input abstraction results corroborate with the underlying validated key natural system environment models. Provide the evidence that builds confidence in the direct inputs.</td>
<td>7.6.4.1</td>
</tr>
<tr>
<td></td>
<td>Evaluate consistency of the abstraction results with the underlying validated key engineered barrier system models.</td>
<td>Perform quantitative and qualitative evaluation of how well direct input abstraction results corroborate the underlying validated key EBS models. Provide the evidence that builds confidence in the direct inputs.</td>
<td>7.6.4.2</td>
</tr>
<tr>
<td></td>
<td>Evaluate consistency of the abstraction results with the underlying validated key drip shield, WP, and waste form degradation and mobilization models.</td>
<td>Perform quantitative and qualitative evaluation of how well the direct input abstraction results corroborate the underlying validated key drip shield, WP, and waste form degradation and mobilization models. Provide the evidence that builds confidence in the direct inputs.</td>
<td>7.6.4.3</td>
</tr>
<tr>
<td></td>
<td>Evaluate consistency of the abstraction results with the underlying validated key disruptive events models.</td>
<td>Perform quantitative and qualitative evaluation of how well the direct input abstraction results corroborate the underlying validated key seismic and igneous disruptive events models. Provide the evidence that builds confidence in the direct inputs.</td>
<td>7.6.4.4</td>
</tr>
<tr>
<td></td>
<td>Evaluate consistency of the abstraction results with the underlying validated biosphere model.</td>
<td>Provide the evidences that build confidence in the direct inputs from the biosphere model to the TSPA-LA Model.</td>
<td>7.6.4.5</td>
</tr>
<tr>
<td>Corroboration of Results with Auxiliary Analyses</td>
<td>Analysis of Single Realizations</td>
<td>Evaluate a realization that contributes significantly to mean annual dose for the Early Failure Modeling Cases.</td>
<td>7.7.1 and 7.7.1[a]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Select a realization each from the Waste Package EF Modeling Case and Drip Shield EF Modeling Case and analyze it to examine how the transport of key radionuclides is affected by coupling various components of the EBS, UZ, and SZ domains following the WP failure under varying physical-chemical-thermal-mechanical conditions. Also select an outlier realization and examine it to understand what leads to the extreme dose.</td>
<td>7.7.1 and 7.7.1[a]</td>
</tr>
</tbody>
</table>
Table 7.1-1[a]. TSPA-LA Model v5.005 Validation Analyses (Continued)

<table>
<thead>
<tr>
<th>Activity Category/Subcategory</th>
<th>Purpose</th>
<th>Activity Description</th>
<th>Document Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evaluate a realization that contributes significantly to mean annual dose for the Igneous Intrusion Modeling Case.</td>
<td>Select a realization from the Igneous Intrusion Modeling Case and analyze it to examine how the transport of key radionuclides is affected by coupling various components of the EBS, UZ, and SZ domains following the waste package failure under varying physical-chemical-thermal-mechanical conditions. Also select an outlier realization and examine it to understand what leads to the extreme dose.</td>
<td>7.7.1 and 7.7.1[a]</td>
<td></td>
</tr>
<tr>
<td>Evaluate a realization that contributes significantly to mean annual dose for the Seismic GM Modeling Case.</td>
<td>Select a realization from the Seismic GM Modeling Case and analyze it to examine how the transport of key radionuclides is affected by coupling various components of the EBS, UZ, and SZ domains following the WP failure under varying physical-chemical-thermal-mechanical conditions. Both the 1,000,000-year and 10,000-year modeling cases were examined.</td>
<td>7.7.1 and 7.7.1[a]</td>
<td></td>
</tr>
<tr>
<td>Evaluate a realization that contributes significantly to mean annual dose for the Nominal Modeling Case.</td>
<td>Select a realization from the Nominal Modeling Case and analyze it to examine how the transport of key radionuclides is affected by coupling various components of the EBS, UZ, and SZ domains. Also evaluate statistical outlier for this modeling case. Also select an outlier realization and examine it to understand what leads to the extreme dose.</td>
<td>7.7.1[a]</td>
<td></td>
</tr>
<tr>
<td>Evaluate a realization that contributes significantly to mean annual dose for the Human Intrusion Modeling Case.</td>
<td>Select a realization from the Human Intrusion Modeling Case and analyze it to examine how the transport of key radionuclides is affected by coupling various components of the EBS, UZ borehole, and SZ domains following the human intrusion event. Also select an outlier realization and examine it to understand what leads to the extreme dose.</td>
<td>7.7.1[a]</td>
<td></td>
</tr>
<tr>
<td>Comparison with Other Simple Models</td>
<td>Compare the TSPA-LA Model component results with a simplified analysis.</td>
<td>Perform a Simplified TSPA Analysis and compare the results with those of the TSPA-LA Model.</td>
<td>7.7.2 and 7.7.2[a]</td>
</tr>
<tr>
<td>Compare with the Energy and Power Research Institute (EPRI) TSPA Analysis.</td>
<td>Develop a comparison of the approach and results of the TSPA independently conducted by EPRI using its code IMARC for the postclosure performance of the Yucca Mountain repository.</td>
<td>7.7.3 and 7.7.3[a]</td>
<td></td>
</tr>
</tbody>
</table>
## Table 7.1-1[a]. TSPA-LA Model v5.005 Validation Analyses (Continued)

<table>
<thead>
<tr>
<th>Activity Category/Subcategory</th>
<th>Purpose</th>
<th>Activity Description</th>
<th>Document Section</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Performance Margin Analyses</strong></td>
<td>Provide objective evidence for assessing performance margin and degree of conservatism or non conservatism in the TSPA-LA Model.</td>
<td>Conduct several auxiliary analyses (see Section 7.7.4 of the parent document for a list) utilizing revisions to selected component models in the TSPA-LA Model, including conceptual or uncertainty alternatives, to assess the performance margin in the TSPA-LA Model and to evaluate whether the TSPA-LA Model dose is underestimated. The analyses include both individual component revisions as well as a combined analysis that incorporates all of the selected component revisions.</td>
<td>7.7.4 and 7.7.4[a]</td>
</tr>
<tr>
<td><strong>Corroboration of Results with Natural Analogues</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cerro Negro</td>
<td>Validation of ASHPLUME for the Volcanic Eruption Modeling Case.</td>
<td>Comparison Cerro Negro ash-fall measurements with the results from ASHPLUME.</td>
<td>7.8.1</td>
</tr>
<tr>
<td>Peña Blanca, Nopal I Uranium Deposit</td>
<td>Validation of the UZ and SZ Transport Model.</td>
<td>Evaluation of geochemical data collected from rock and water samples with respect to distance from the Nopal I ore deposit.</td>
<td>7.8.2</td>
</tr>
<tr>
<td><strong>Independent Technical Reviews</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TSPA-VA Peer Review</td>
<td>Evaluate the TSPA-VA methodology and prediction of the future behavior of the total system.</td>
<td>Performed peer review of the TSPA-VA and the supporting process models. The review was conducted by an independent group of external experts from 1997 to 1999.</td>
<td>7.9.1</td>
</tr>
<tr>
<td>TSPA-SR Peer Review</td>
<td>Evaluation of the TSPA-SR for methodology and ability to meet the needs for SR and future LA compliance.</td>
<td>Performed peer review of the TSPA-SR and selected supporting documents to evaluate the approach used in the performance assessment, and how well the TSPA-SR and the future TSPA-LA Model needs were addressed. The review was conducted by an international panel of experts managed by the OECD/NEA in 2002.</td>
<td>7.9.2</td>
</tr>
<tr>
<td>Draft TSPA-LA Technical Review</td>
<td>Evaluate the earlier draft iterations of the TSPA-LA Model as they were being drafted as to the degree of validation of the model for its intended purpose.</td>
<td>Perform technical review on the evaluation of the degree to which the draft TSPA-LA Model was valid for its intended purpose for the 10,000-year compliance period for which the model was prepared. The review was conducted by a team of experts during 2004, 2005, and early part of 2006.</td>
<td>7.9.3</td>
</tr>
</tbody>
</table>
7.2[a] COMPUTER CODE AND INPUT VERIFICATION

7.2.1[a] Selection and Verification of the Integrated System Software: GoldSim

A revised version of the GoldSim software (GoldSim V9.60.300, STN: 10344-9.60-03 [DIRS 184387]) was used in all updated TSPA-LA Model results reported in this addendum. Information about GoldSim is discussed in Section 7.2.1 of the parent document.

The revised version of GoldSim was qualified in accordance with IM-PRO-004, *Qualification of Software*. The updated software was obtained from Software Configuration Management in accordance with IM-PRO-003, *Software Management*, and was installed in accordance with installation test instructions listed in *User Information Document for: GoldSim Version 9.60* (DOE 2007 [DIRS 181108], Section 3.1). GoldSim was used to develop the analyses for the TSPA-LA Model within the limitations and the range of verification guidance presented in Appendix G of the *User's Guide, GoldSim Probabilistic Simulation Environment, Version 9.60* (GoldSim Technology Group 2007 [DIRS 181727]). Additional information regarding the GoldSim software is discussed in Section 3.8 of the parent document, Section 3.8[a] of this addendum, and in the documents listed in Table 3-8[a].

7.2.2[a] Verification of Dynamically Linked Libraries as Single Modules and in an Integrated System

No change.

7.2.3[a] Verification of Inputs in Total System Performance Assessment Input Database

Parameters used in the analyses presented in this addendum are documented in the TSPA Input Database described in Section 4.7 of the parent document, with additional detail provided in Section 7.2.3 of the parent document. Each TSPA-LA Model simulation described in this addendum accesses the TSPA Input Database in order to obtain values for each model’s parameters from sources listed in Table 4-1 of the parent document and Table 4-1[a] of this addendum. Parameter values are maintained as originally entered, without transformation or post-processing, and are manually entered into the database (this is described in more detail in Section 7.2.3 of the parent document). Figure 4-3 of the parent document shows the structural framework of the TSPA Input Database, which is described in Section 4.7 of the parent document.

The value of every parameter is checked and verified before using it for a performance-assessment analysis. Any discovered errors are documented in the TSPA-LA Model Log; corrected values are entered into the database and, if determined to be necessary by an impact analysis (e.g., Appendix P of the parent document), the impacted calculations are performed again. The parameter verification is documented on the Parameter Verification Form (Section 4.7 of the parent document). Only users with access to the TSPA-LA Model’s controlled-access input database can verify parameter values. The verification process includes recording the checker’s name, along with the date and time, in order to identify the last user who changed any parameter categories. Strict control of access and documentation increases confidence in the security, integrity, and traceability of information entered into, or downloaded from, the TSPA Input Database. In this same way, the TSPA Input Database was verified with...
the new information (listed in Table 4-1[a]) that supports the analyses documented in this addendum.

7.2.4[a] Verification of Single Model Components

The TSPA-LA Model is composed primarily of submodels derived from abstraction models that are documented in analysis and/or model reports. Verification and validation activities used to improve confidence in numerical models implemented in the TSPA-LA Model are described in Section 7.2.4 of the parent document. As discussed in Section 7.2.4 of the parent document, the approach to verification is to compare TSPA-LA Model file results with results of stand-alone implementations reported in analysis and/or model reports or validation test reports, where applicable. Additional verification activities that were not included in the parent document are presented in Section 7.2.4.1.12[a] of this addendum. These additional verification activities were conducted only for the Human Intrusion Modeling Case. Verification tests of input and submodels specific to the Human Intrusion Modeling Case included verifying inputs in the TSPA database, verifying the submodels (such as the borehole pipe model), and verifying proper coupling among submodels.

7.2.4.1[a] Verification Results

The results of the submodel implementation verification activities are presented in Sections 7.2.4.1.1 through 7.2.4.1.11 of the parent document. These apply to TSPA-LA Model v5.005 without change. One additional verification of the Human Intrusion Submodel is provided in Section 7.2.4.1.12[a] of this addendum. This verification activity consists of verifying Human Intrusion Submodel inputs in the TSPA-LA Model database, verifying selected Human Intrusion Submodels (such as the borehole pipe model), and verifying proper coupling among Human Intrusion Submodels. The results of the verification of the Human Intrusion Submodel (output DTN: MO0801TSPAMVAC.000 [DIRS 185080]) are discussed in Section 7.2.4.1.12[a].

7.2.4.1.1[a] Drift Seepage

No change.

7.2.4.1.2[a] Drift Wall Condensation Submodel Verification

No change.

7.2.4.1.3[a] Engineered Barrier System Chemical Environment

No change.

7.2.4.1.4[a] Waste Package and Drip Shield Degradation

No change.

7.2.4.1.5[a] Waste Form Degradation and Mobilization

No change.
7.2.4.1.6[a] Engineered Barrier System Transport
No change.

7.2.4.1.7[a] Unsaturated Zone Transport
No change.

7.2.4.1.8[a] Saturated Zone Flow and Transport
No change.

7.2.4.1.9[a] Biosphere
No change.

7.2.4.1.10[a] Igneous Scenario Class Modeling Cases
No change.

7.2.4.1.11[a] Seismic Scenario Class Modeling Cases
No change.

7.2.4.1.12[a] Human Intrusion Scenario
Verification of the Human Intrusion Scenario focuses on an alternate implementation of the UZ Transport Submodel where the radionuclide transport from the engineered barrier system (EBS) to the saturated zone (SZ) is confined to a borehole penetrating the waste package (WP) and extending through the unsaturated zone (UZ) to the SZ. A simplified deterministic analysis was performed in order to verify the implementation of the Human Intrusion Submodel. The verification test utilized one Latin hypercube sample (LHS) vector for the epistemic and aleatory parameter values. Beginning at 200,000 years into the simulation, the source term for the realization was redefined as a single release into the EBS of one gram of the non-sorbing radionuclide $^{129}$I and one gram of the sorbing radionuclide $^{237}$Np. The rest of the radionuclide inventory was set to zero for the simulation. This allowed a comparison of the simple mass release from the EBS to the mass leaving the borehole at the water-table. A specific percolation rate of 25 mm/yr was assigned for the simulation and was used to check that both the EBS and the borehole-pipe element were using the same rate (as specified in the model implementation, Section 6.7.3.2 of the parent document) and to approximate the time needed for the cumulative mass release from the borehole to reach 0.5 grams for a simulation without considering matrix diffusion. Two simulations were performed: the first allowed for matrix diffusion into the surrounding rock matrix and the second did not consider matrix diffusion. The selected realization is number 8,309 (out of 9,000 total realizations) and represents epistemic vector 277 and aleatory vector 29 (output DTN: MO0710ADTSPAWO.000 [DIRS 183752]). The aleatory vector 29 is defined as a CSNF WP release from a WP located in percolation subregion 4.

The source term was implemented by adding the radionuclide mass for $^{129}$I and $^{237}$Np to the CSNF interface cell representing the WP outer corrosion barrier (OCB) during the 250-year
timestep beginning 200,000 years into the simulation. To ensure that most of the mass would reach the borehole rapidly, no diffusion was allowed from the interface cell back to the upstream cell representing the corrosion products domain. The selected percolation rate was implemented by changing the input value for the percolation rate for the borehole to 25 mm/yr for any CNSF WP release from a WP located in percolation subregion 4. As part of this verification, simulation results were examined to make sure that the CSNF EBS seepage feed (model parameter \textit{Seepage\_Flux\_Feed\_EBS}) was set to 0.00081 m$^3$/year, the product of the borehole area (0.0324 m$^2$), and the percolation rate of 25 mm/yr. The outflow rate from the borehole pipe element was also checked and was given to be 2.56674 x 10^{-11} m$^3$/s (0.00081 m$^3$/year).

For both simulations, 99.99 percent of the $^{129}$I and 99.98 percent of the $^{237}$Np are released from the EBS into the borehole in the first timestep. Also, $^{233}$U produced by decay of $^{237}$Np is released from the EBS. The results for the borehole release to the SZ from the two simulations are presented on Figure 7.2-17[a]. For the simulation with matrix diffusion considered, it can be seen on Figure 7.2-17[a] that the total release of $^{129}$I from the borehole is very close to the applied EBS mass release of one gram (0.9999 grams). Because of decay, the total release of $^{237}$Np is only 0.9785 g. When the product of the mass release of $^{233}$U, its daughter product from the borehole and the ratio of the atomic weights of $^{237}$Np and $^{233}$U, is added to the $^{237}$Np release the total release increases to 0.9970 g. Note that a very small amount (3.539 x 10^{-7} g) of $^{229}$Th, $^{233}$U’s daughter product, is also produced. For $^{129}$I, there is a short delay of the mass release associated with the diffusion of mass between the fracture and rock matrix. This delay is approximately 1,250 years as defined by the 0.5 gram breakthrough level in the cumulative results. For $^{237}$Np, the delay is approximately 64,000 years. Note that the matrix retardation for $^{237}$Np in this simulation is 47.8, which is close to 51.2, the ratio of the breakthrough time of $^{237}$Np to that of $^{129}$I, which has a retardation coefficient of 1.0.

As shown on Figure 7.2-17[a], for the simulation without matrix diffusion, most of the $^{129}$I and $^{237}$Np mass leaving the EBS has exited the borehole within one timestep (250 years). Based on the volumetric rate of water entering the borehole (0.00081 m$^3$/year), the fracture area of 0.0004211 m$^2$ within the borehole cross-section and the fracture saturation of 0.0253, over the 190 m borehole length (Section 6.7.3.2 of the parent document) the advective transport velocity in the fracture, is approximately 76 m/year, which translates into an advective transport time of 2.5 years. A comparison of the time between the mass application and the time of the 0.5 gram breakthrough level in the cumulative mass release curve, with a transport time of 2.5 years, is not possible because of the coarseness of the simulation timesteps. By the end of the timestep starting at 200,000 years, 99.04 percent of $^{129}$I and 99.03 percent of $^{237}$Np have exited the borehole. This release pattern is consistent with a very short transport time through the borehole when matrix diffusion is not considered.

The analysis presented above verifies that the UZ Transport Submodel for the Human Intrusion Scenario is implemented correctly. This verification test for the submodel specific to the Human Intrusion Modeling Case, combined with the verification of the TSPA-LA Model’s submodels documented in the parent document, are used to assert that the Human Intrusion Scenario is verified.
7.2.5[a] Verification of Coupling among Submodels and Model Components

No change.

7.2.6[a] Verification of Range of Applicability of Submodels and Model Components

A discussion of the verification of the range of applicability of submodels and model components is provided in Section 7.2.6 of the parent document. An assessment of the range of validity for all TSPA-LA Model submodels (output DTN: MO0709TSPALAMO.000 [DIRS 182981]) was conducted over the specified range of validity. The summary results of this assessment were inadvertently left out of Section 7.2.6 of the parent report. The summary results of this verification assessment are documented below. The records that document the implementation and checking of the TSPA-LA Model are located in the relevant records package.

During the development of the TSPA-LA Model, fatal error encounters and flag setting conditions signaling an out-of-range condition did occur. In many cases, when an out-of-range condition occurred, the provided abstractions were revised to preclude the occurrence of the out-of-range condition. The abstractions were revised to: (1) constrain the calculated values by removing undue uncertainty that could broaden the calculated results, (2) expand the range of validity of the abstraction, or (3) provide additional guidance on how to handle out-of-range conditions. However, an assessment of the range of validity for all TSPA-LA Model submodels (output DTN: MO0709TSPALAMO.000 [DIRS 182981]) revealed that for the 1,000,000-year performance runs, three submodels of the Waste Form Degradation and Mobilization Model Component were applied below the lower temperature limit in the specified range of validity. For the 10,000-year simulations, the temperatures remain within the range of validity.

In the 1,000,000-year performance runs, WPs return to ambient temperatures in the modeled duration. The ambient temperature from the EBS TH Environment Submodel (Section 6.3.2) can be as low as 17°C. The lower temperature limit for the In-Package Chemistry Abstraction (SNL 2007 [DIRS 180506], Section 1[a]) and the Dissolved Concentration Limits Abstraction (SNL 2007 [DIRS 177418], Section 6.3.3.3) is 25°C. The lower temperature limit for the HLW Glass Waste Form Degradation Abstraction is 20°C (BSC 2004 [DIRS 169988], Section 1.2). As discussed below, the application of these three submodels below the stated range of applicability is not expected to have a significant affect on the EBS release calculations; therefore, the TSPA-LA Model applies the provided abstractions below the lower temperature limits without further modifications.

The lower temperature limit for the range of applicability of the In-Package Chemistry Abstraction is 25°C. The pH and ionic strength abstractions were developed for conditions at 25°C, but there is no explicit temperature dependence in the abstractions for pH and ionic strength within the waste form domain. Through the use of sensitivity studies and conservative modeling choices, the effects of temperature were determined to be negligible and the range of applicability was extended up to temperatures of 100°C (SNL 2007 [DIRS 180506], Section 6.6[a] and 8.1[a]). Because of the pH buffering capacity in the waste form cells results in a high degree of confidence in the minimum and maximum pH at 25°C (SNL 2007 [DIRS 180506], Section 6.10.8.1[a]) and because sensitivity studies reveal that temperature has a
negligible effect on ionic strength (SNL 2007 [DIRS 180506], Section 6.6.6 and 6.6[a]), the application of pH and ionic strength abstractions developed at 25°C to temperatures as low as 17°C is not anticipated to produce results that are outside the range of uncertainty captured in the abstractions for pH and ionic strength.

The lower temperature limit for the range of applicability of the Dissolved Concentration Limits Abstraction is 25°C. Because actinides in carbonate systems, such as those that will prevail in the EBS, have retrograde solubility, abstractions for the solubility of actinides were developed for conditions at 25°C and include additional uncertainty to expand the temperatures range of applicability up to 100°C, but there is no explicit temperature dependence in the abstractions for actinide solubility in the EBS (SNL 2007 [DIRS 177418], Section 6.3.3). The TSPA-LA Model applies the Dissolved Concentration Limits Abstraction at temperatures below 25°C. Because actinides have retrograde solubility, it is possible that dissolved concentration limits below 25°C could be higher than those implemented in the TSPA-LA Model. But because the Dissolved Concentration Limits Abstraction includes additional uncertainty to account for differences in temperature conditions (SNL 2007 [DIRS 177418], Section 6.3.3), it is anticipated that dissolved concentration limits at lower temperatures would be within the range of uncertainty captured in the Dissolved Concentration Limits Abstraction. Radium solubility is higher at higher temperatures and the abstraction developed at 100°C is conservatively applied to all temperatures below 100°C.

The lower temperature limit for the range of applicability of the HLW Glass Waste Form Degradation Abstraction is 20°C. The HLW Glass Waste Form Degradation Abstraction has explicit temperature dependence in the rate expression and below 20°C, the TSPA-LA Model applies the applicable temperature in the rate expression. The lower temperature limit of the HLW Glass Waste Form Degradation Abstraction was determined by the ranges considered in the experimental results used to validate the rate model (BSC 2004 [DIRS 169988], Section 7.3), which showed that the Arrhenius relationship for glass degradation rate is maintained between 20°C and 90°C. This relationship is not anticipated to change between 17°C and 20°C. Therefore, applying the rate model at 17°C to high-level radioactive waste (HLW) glass that is still intact within the waste form domain when the WP temperatures drop below 20°C, is not expected to have any effect on mass transport calculations.

7.3[a] MODEL STABILITY

7.3.1[a] Statistical Stability

As outlined in Section 7.3 of the parent document, the calculated total mean annual dose is an expected value over epistemic and aleatory uncertainties of estimates of annual dose (Equation 7.3-1 of the parent document). The expectation of annual dose over aleatory uncertainty is evaluated first, the result of which is called (for brevity) ‘expected annual dose’. The accuracy of the integral over aleatory uncertainty is discussed in Section 7.3.2 of the parent document. The integral of expected annual dose over epistemic uncertainty is referred to as the mean annual dose and is evaluated numerically by using a Monte Carlo technique. The mean annual dose is statistically stable if the sample size employed in the Monte Carlo technique produces an adequate estimate of the mean annual dose.
Section 7.3.1 of the parent document presents analyses that demonstrate the statistical stability of the total mean annual dose (summed over all modeling cases) and the mean annual dose for each modeling case for TSPA-LA Model v5.000. This section compares uncertainty and sensitivity analyses generated by TSPA-LA Model v5.000 and TSPA-LA Model v5.005 and concludes that the results from TSPA-LA Model v5.005 are also statistically stable. Additionally, this section describes the bootstrap sampling procedure (Davison and Kuonen 2002 [DIRS 184463]) used in this addendum to compute confidence intervals for the total mean annual dose for TSPA-LA Model v5.005. Confidence intervals are presented for both 20,000 years (Figure 7.3.1-47[a]) and 1,000,000 years (Figure 7.3.1-48[a]).

7.3.1.1[a] Replicated Sampling Procedure (Procedure for Demonstrating Stability)
No change.

7.3.1.2[a] Stability Analysis Results for Modeling Cases

Human Intrusion Modeling Case—Because of the error involving the timesteps used in the Human Intrusion Modeling Case (Appendix P, Table P-6, Item 6 of the parent document), coarseness of the temporal stability analysis for TSPA-LA Model v5.000 (Section 7.3.1.2), and absence of sensitivity analysis results for the Human Intrusion Modeling Case in the parent document, the statistical stability of the Human Intrusion Modeling Case is demonstrated in this addendum by repeating the replicated sampling procedure. Figure 7.3.1-14a[a] shows the mean annual dose for each of the three replicates of the Human Intrusion Modeling Case, along with the median and the 5th and 95th percentiles of the distribution of the expected annual dose. Figure 7.3.1-14b[a] displays the confidence interval for this modeling case. The high degree of similarity among replicates and the very narrow confidence interval indicates that the mean annual dose for this modeling case is estimated accurately, and the sample size of 300 is adequate.

7.3.1.3[a] Stability Analysis Results for Total Mean Annual Dose
No change.

7.3.1.4[a] Conclusion
No change.

7.3.1.5[a] Statistical Stability of Model Results
As discussed in Section 7.3.1 of the parent document, a replicated sampling procedure provides an effective approach to estimating the potential sampling error in quantities derived from Latin hypercube sampling (Iman 1982 [DIRS 146012]). With this procedure, the LHS is repeatedly generated with different random seeds. Each LHS is used to produce an estimate of the mean annual dose. The ensemble of estimates of the mean annual dose is used to compute an overall mean and standard error. Confidence intervals for the mean annual dose are estimated by means of the \( t \)-distribution. Appendix J, Section J4.10, of the parent document provides details on the replicated sampling procedure and the application of the \( t \)-distribution. The analysis presented in the parent document concludes that the LHS size of 300 is sufficient to produce a statistically stable estimate of the total mean annual dose and of the mean annual dose for each modeling
case. The confidence intervals provide a quantitative assessment of the accuracy of the estimates of total mean annual dose and mean annual dose for each modeling case.

Section 4[a] identifies additional direct inputs used in generating the TSPA-LA Model results presented in this addendum. Appendix P[a] lists the changes and corrections made to the TSPA-LA Model in updating from v5.000 to v5.005. Model changes summarized in Appendix P[a] are relatively minor in that the features, events, and processes (FEPs) that determine radionuclide releases from the repository remain constant in the TSPA-LA Model (also see Appendix P of the parent document). Moreover, the LHSs used to generate results from the two models are nearly identical. Table 7.3.1-1[a] summarizes the differences in the sampled parameters in the two LHSs. Both LHSs are of the same size (300) and, with three exceptions, the pairing of sampled values is the same in each LHS. The technique chosen to correct the distributions for FHII_Isotherm_k_CP_a and FHII_Isotherm_s_CP_a resulted in new orderings of the sampled values for these parameters, and the removal of an unintended correlation between WRIP_beta_rand_a and PCE_Delta_pCO2_a (Table K3-2) resulted in a new ordering for the sampled values for WRIP_beta_rand_a. As a consequence, the two LHSs differ in the pairing of the sampled values for these three parameters with the sampled values of the other parameters. Because the changes are relatively minor and both model versions use nearly identical LHSs, the replicated sampling procedure is not repeated with TSPA-LA Model v5.005, except for the Human Intrusion Modeling Case (Section 7.3.1.2[a]). Instead, results from TSPA-LA Model v5.000 are compared to results from TSPA-LA Model v5.005 to demonstrate the statistical stability of results from TSPA-LA Model v5.005.

7.3.1.5.1[a] Expected Annual Dose for Nominal Modeling Case

Figure 7.3.1-17[a] shows the distribution of expected annual dose for 1,000,000 years and statistics for this distribution for the Nominal Modeling Case for (a) TSPA-LA Model v5.000 and (b) TSPA-LA Model v5.005. The general trends and the range of uncertainty in expected annual dose are similar for both models. Because of the correction of the error in computing the weld volume (Appendix P, Section P6, of the parent document), weld flaws are roughly three times more likely to occur in the results from TSPA-LA Model v5.005 than in the results from TSPA-LA Model v5.000. Consequently, weld failures occur earlier in the TSPA-LA Model v5.005 results, as is evident in the few realizations showing expected dose prior to 100,000 years. Despite the earlier occurrence of WP failures in the results from TSPA-LA Model v5.005, Figure 7.3.1-18[a] shows that the statistics for the distribution of expected annual dose are similar for both models, and the scatterplots in Figure 7.3.1-19[a] illustrate (at the selected times) that the expected annual dose is the same for most epistemic sample elements. Expected annual dose increases in TSPA-LA Model v5.005 results after 600,000 years for a few sample elements are due to the corrections to models for waste form and iron oxyhydroxide colloids (Appendix P, Section P18, and Table P-6, Items 5 and 12 of the parent document). Comparison of Figure K4.5-2a of the parent document and Figure K4.5-2a[a] demonstrates that the uncertain inputs that predominately determine uncertainty in expected annual dose are almost identical for both model versions. Because (1) model changes are relatively minor, (2) both models use nearly identical LHSs of the same size, (3) model results show close agreement in both the magnitude and range of uncertainty of expected annual dose, (4) the uncertain inputs that predominately determine uncertainty in expected annual dose are identical for both versions, and (5) TSPA-LA Model v5.000 produces a statistically stable estimate of mean annual dose.
(demonstrated in Section 7.3.1.2 of the parent document), it is reasonable to conclude that the sample size used in TSPA-LA Model v5.005 produces a statistically stable estimate of mean annual dose for the Nominal Modeling Case.

7.3.1.5.2 Expected Annual Dose for Drip Shield Early Failure Modeling Case

Figure 7.3.1-20 and Figure 7.3.1-21 show statistics for the distribution of expected annual dose for 20,000 years and 1,000,000 years, respectively, for the Drip Shield Early Failure (EF) Modeling Case. The corresponding distributions for expected annual dose from TSPA-LA Model v5.000 and TSPA-LA Model v5.005 are shown on Figure 8.2-3 of the parent document and Figure 8.2-3, respectively. The general trends and the range of uncertainty in expected annual dose are similar for both models. The small but general reduction in expected annual dose for TSPA-LA Model v5.005 results for 20,000 years (Figures 7.3.1-20 and 7.3.1-22) is due to the change in the calculation of the seepage fraction (Appendix P, Section P2). Figure 7.3.1-22 and Figure 7.3.1-23 show that, for most sample elements, the expected annual dose is similar in both model versions. The increase in expected annual dose in TSPA-LA Model v5.005 results for a few sample elements is due to the corrections to models for waste form and iron oxyhydroxide colloids (Appendix P, Section P18, and Table P-6, Items 5 and 12 of the parent document). In particular, the outlying value of expected annual dose at 1,000 years is due to a contribution to expected annual dose from $^{241}$Am sorbed to iron oxyhydroxide colloids, which transports relatively rapidly through the natural barriers. For most sample elements, $^{241}$Am contributes negligibly to expected annual dose in both model versions. The decrease in expected annual dose in TSPA-LA Model v5.005 results for a few sample elements in Figure 7.3.1-23 is due to the change in longitudinal dispersivity, which reduces the contribution to expected annual dose of $^{226}$Ra (Appendix P, Section P15 of the parent document). Despite these differences, Figure 7.3.1-22 and Figure 7.3.1-23 demonstrate that the distribution of expected annual dose is similar for both model versions.

The comparison of Figure K5.7.1-2a of the parent document and Figure K5.7.1-2a demonstrates that the uncertain inputs that predominate in the uncertainty in expected annual dose before 10,000 years are almost identical for both model versions; the comparison of Figure K5.7.1-4a and Figure K5.7.1-4a shows the same conclusion after 10,000 years. Moreover, Section 7.7.1.2 and Section 7.7.1.2 demonstrate that the processes affecting radionuclide releases are essentially unchanged from TSPA-LA Model v5.000. It is reasonable to conclude that the sample size used in TSPA-LA Model v5.005 produces a statistically stable estimate of mean annual dose for the Drip Shield EF Modeling Case because (1) model changes are relatively minor, (2) both models use nearly identical LHSs of the same size, (3) model results show close agreement in both the magnitude and range of uncertainty of expected annual dose, (4) the uncertain inputs that predominate in the uncertainty in expected annual dose are identical for both versions, and (5) TSPA-LA Model v5.000 produces a statistically stable estimate of mean annual dose (demonstrated in Section 7.3.1.2 of the parent document).

7.3.1.5.3 Expected Annual Dose for Waste Package Early Failure Modeling Case

Figure 7.3.1-24 and Figure 7.3.1-25 show statistics for the distribution of expected annual dose for 20,000 years and 1,000,000 years, respectively, for the Waste Package EF Modeling Case. The corresponding distributions for expected annual dose from TSPA-LA Model v5.000
and TSPA-LA Model v5.005 are shown on Figure 8.2-5 of the parent document and Figure 8.2-5[a], respectively. The general trends and the range of uncertainty in expected annual dose are similar for both models. Expected annual dose between about 10,000 years and 14,000 years is generally smaller in TSPA-LA Model v5.005 results as shown in Figure 7.3.1-24[a] due to corrections in the calculations for the seepage fraction (Appendix P, Section P2). This item is addressed by TSPA-LA Model v5.005 in Section 6.3.3[a]. Figure 7.3.1-26[a] and Figure 7.3.1-27[a] show that the expected annual dose is the same for most epistemic sample elements. The decrease in expected annual dose (Figure 7.3.1-27[a]) in TSPA-LA Model v5.005 results for a few sample elements is due to the change in longitudinal dispersivity, which reduces the contribution to expected annual dose of $^{226}$Ra (Appendix P, Section P15 of the parent document). The comparison of Figure K5.7.2-2a of the parent document and Figure K5.7.2-2a[a] demonstrates that the uncertain inputs that predominately determine uncertainty in expected annual dose before 10,000 years are identical for both model versions; the comparison of Figure K5.7.2-4a of the parent document and Figure K5.7.2-4a[a] shows the same conclusion after 10,000 years. Moreover, Section 7.7.1.1 of the parent document and Section 7.7.1.1[a] demonstrate that the processes affecting radionuclide releases are essentially unchanged from TSPA-LA Model v5.000. Because of these similarities, and because TSPA-LA Model v5.000 produces a statistically stable estimate of mean annual dose for the Waste Package EF Modeling Case (as demonstrated in Section 7.3.1.2 of the parent document), it is reasonable to conclude that the sample size used in TSPA-LA Model v5.005 produces a statistically stable estimate of mean annual dose for the Waste Package EF Modeling Case.

**7.3.1.5.4[a] Expected Annual Dose for Igneous Intrusion Modeling Case**

Figure 7.3.1-28[a] and Figure 7.3.1-29[a] show statistics for the distribution of expected annual dose for 20,000 years and 1,000,000 years, respectively, for the Igneous Intrusion Modeling Case. The corresponding distributions for expected annual dose from TSPA-LA Model v5.000 and TSPA-LA Model v5.005 are shown on Figure 8.2-7 of the parent document and Figure 8.2-7[a], respectively. The general trends and the range of uncertainty in expected annual dose are similar for both models, although the expected annual dose is generally reduced in magnitude after 10,000 years in the results from TSPA-LA Model v5.005. This reduction is a consequence of the corrected distribution for the longitudinal dispersivity (LDISP in Table K3-2), as described in Appendix P, Section P15 of the parent document. Figure 7.3.1-30[a] and Figure 7.3.1-31[a] show that, for most epistemic sample elements, the expected annual dose is the same for both models. However, prior to 3,000 years, for a few epistemic sample elements the expected annual dose is much higher in the results from TSPA-LA Model v5.005, due to the corrections to models for iron oxyhydroxide colloids (Appendix P, Section P18, and Table P-6, Items 5 and 12 of the parent document). In particular, the outlying values of expected annual dose at 1,000 years are due to contributions to the expected annual dose from $^{241}$Am sorbed to iron oxyhydroxide colloids, which transport relatively rapidly through the natural barriers. For most sample elements, $^{241}$Am contributes negligibly to expected annual dose in either model version. At 100,000 years, the outlying values of expected annual dose in TSPA-LA Model v5.005 results are due to contributions to expected annual dose from $^{239}$Pu sorbed to iron oxyhydroxide colloids, which were not observed in the results from TSPA-LA Model v5.000 due to the errors affecting iron oxyhydroxide colloids. Additionally, after 100,000 years, the expected annual dose for most epistemic sample elements is somewhat less in the results from TSPA-LA Model v5.005; for a few sample
elements, the expected annual dose is much lower than in the results from TSPA-LA Model v5.000. The reduction in expected annual dose is attributable to the reduction in the contribution of $^{226}$Ra (compare Figure 8.2-8b of the parent document and Figure 8.2-8b[a]), which in turn results from the corrected distribution for the longitudinal dispersivity (Appendix P, Section P15 of the parent document).

The comparison of Figure K6.7.1-2a of the parent document and Figure K6.7.1-2a[a] demonstrates that the uncertain inputs that predominately determine uncertainty in expected annual dose before 10,000 years are the same for both model versions; the comparison of Figure K6.7.2-2a of the parent document and Figure K6.7.2-2a[a] shows the same conclusion after 10,000 years. Moreover, Section 7.7.1.3 of the parent document and Section 7.7.1.3[a] demonstrate that the processes affecting radionuclide releases are essentially unchanged from TSPA-LA Model v5.000. Because of these similarities, and because TSPA-LA Model v5.000 produces a statistically stable estimate of mean annual dose for the Igneous Intrusion Modeling Case (as demonstrated in Section 7.3.1.2 of the parent document), it is reasonable to conclude that the sample size used in TSPA-LA Model v5.005 produces a statistically stable estimate of mean annual dose for the Igneous Intrusion Modeling Case.

7.3.1.5.5[a] Expected Annual Dose for Volcanic Eruption Modeling Case

No changes to the TSPA-LA Model affected the evaluation of the Volcanic Eruption Modeling Case. Therefore, the results for this modeling case are not different from those reported in the parent document.

7.3.1.5.6[a] Expected Annual Dose for Seismic Ground Motion Modeling Case

Figure 7.3.1-32[a] shows statistics for the distribution of expected annual dose for 20,000 years for the Seismic GM Modeling Case. The corresponding distributions for expected annual dose from TSPA-LA Model v5.000 and TSPA-LA Model v5.005 are shown in Figure 8.2-11a of the parent document and Figure 8.2-11a[a], respectively. The general trends and the range of uncertainty in expected annual dose are similar for both models. Figure 7.3.1-33[a] shows that expected annual dose is essentially unchanged for all epistemic sample elements. The high degree of similarity in the 20,000-year results from both model versions can be attributed to the simplifications to the seismic damage abstractions for this modeling case (Section 7.3.2.6 of the parent document) and to the dominant contribution of $^{99}$Tc to expected annual dose for this modeling case (Figure 8.2-12a of the parent document and Figure 8.2-12a[a]). The changes to the seismic damage models summarized in Appendix P[a] do not affect the 20,000-year results because of the simplifications to the seismic damage abstractions (Section 7.3.2.6 of the parent document), and few of the errors detailed in Appendix P have any effect on the mobilization or transport of $^{99}$Tc. The comparison of Figure K7.7.1-2a of the parent document and Figure K7.7.1-2a[a] shows that the uncertain model inputs that are important contributors to the uncertainty in expected annual dose for the Seismic GM Modeling Case before 10,000 years are the same for both model versions. Because of these similarities, and because TSPA-LA Model v5.000 produces a statistically stable estimate of mean annual dose for the Seismic GM Modeling Case (as demonstrated in Section 7.3.1.2 of the parent document), it is reasonable to conclude that the sample size used in TSPA-LA Model v5.005 produces a statistically stable estimate of mean annual dose for the Seismic GM Modeling Case for 20,000 years.
Figure 7.3.1-34[a] shows the distribution of expected annual dose for 1,000,000 years and statistics for this distribution for the Seismic GM Modeling Case for (a) TSPA-LA Model v5.000 and (b) TSPA-LA Model v5.005. Due primarily to improving upon the conservative treatment of synergisms between seismic events and nominal corrosion processes (Appendix P, Section P3 of the parent document), in many sample elements fewer CSNF WPs experience seismic damage in the results from TSPA-LA Model v5.005 (shown by a comparison of Figure 8.1-5b of the parent document and Figure 8.1-5b[a]), which in turn results in the reduction in magnitude of expected annual dose before about 300,000 years. Because seismic damage occurs to fewer CSNF WPs, these WPs remain intact until compromised by nominal corrosion processes, which are relatively unchanged (see discussion of Nominal Modeling Case results in Section 7.3.1.5.1[a]). Thus, after 300,000 years, the general trends in expected dose are more representative of the expected dose due to nominal corrosion processes (compare Figure 7.3.1-34b[a] to Figure 7.3.1-17[a]). Statistics for the distribution of expected annual dose for the Seismic GM Modeling Case for 1,000,000 years are shown on Figure 7.3.1-35[a]; Figure 7.3.1-36[a] shows comparisons of expected annual dose for each sample element at selected times. These figures illustrate the general reduction in expected annual dose due to improving the treatment of synergisms between seismic damage and nominal corrosion processes. However, for a few sample elements, expected annual dose is higher at 600,000 years (Figure 7.3.1-36c[a]) and 1,000,000 years (Figure 7.3.1-36d[a]) in the results from TSPA-LA Model v5.005. For these sample elements, increases in expected annual dose are observed at these times because WPs are less likely to be breached by earlier seismic events, which in turn means that more of the waste inventory is contained in the EBS until later times, when WPs are breached due to general corrosion. In addition, the corrections to the calculation of stability of iron oxyhydroxide colloid can lead to larger plutonium releases for those sample elements in which general corrosion failures occur prior to 1,000,000 years.

Despite the differences evident in expected annual dose, Figure 7.3.1-35[a] shows that the range of uncertainty in expected annual dose is similar for both model versions. The comparison of Figure K7.7.2-2a of the parent document and Figure K7.7.2-2a[a] shows that the uncertain model inputs that are important contributors to the uncertainty in expected annual dose for the Seismic GM Modeling Case for 1,000,000 years are generally the same for both model versions. Section 7.7.1.4 of the parent document and Section 7.7.1.4[a] demonstrate that, once WP failure has occurred, the subsequent processes affecting radionuclide releases are essentially unchanged from TSPA-LA Model v5.000. Because of these similarities, and because TSPA-LA Model v5.000 produces a statistically stable estimate of mean annual dose for the Seismic GM Modeling Case (as demonstrated in Section 7.3.1.2 of the parent document), it is reasonable to conclude that the sample size used in TSPA-LA Model v5.005 produces a statistically stable estimate of mean annual dose for the Seismic GM Modeling Case for 1,000,000 years.

7.3.1.5.7[a] Expected Annual Dose for Seismic Fault Displacement Modeling Case

Figure 7.3.1-37[a] and Figure 7.3.1-38[a] show statistics for the distribution of expected annual dose for 20,000 years and 1,000,000 years, respectively, for the Seismic Fault Displacement (FD) Modeling Case. The corresponding distributions for expected annual dose from TSPA-LA Model v5.000 and TSPA-LA Model v5.005 are shown on Figure 8.2-13 of the parent document and Figure 8.2-13[a], respectively. The general trends and the range of uncertainty in expected annual dose are similar for both models. Figure 7.3.1-39[a] and Figure 7.3.1-40[a] show that, for
most epistemic sample elements, the expected annual dose is the same for both models. However, prior to 3,000 years, for a few epistemic sample elements the expected annual dose is much higher in the results from TSPA-LA Model v5.005, due to the corrections to models for iron oxyhydroxide colloids (Appendix P, Section P18, and Table P-6, Items 5 and 12 of the parent document). Additionally, after 100,000 years, the expected annual dose for a few sample elements is much lower than in the results from TSPA-LA Model v5.000 due to the corrected distribution for the longitudinal dispersivity (Appendix P, Section P15 of the parent document). The comparison of Figure K7.8.1-2a of the parent document and Figure K7.8.1-2a[a] demonstrates that the uncertain inputs that predominately determine uncertainty in expected annual dose before 10,000 years are similar for both model versions; the comparison of Figure K7.8.2-2a of the parent document and Figure K7.8.2-2a[a] shows the same conclusion after 10,000 years. Moreover, because the processes that determine radionuclide releases following a fault displacement are similar to those investigated for the early failure modeling cases (i.e., advection and diffusion), and these processes are essentially the same in the Early Failure Modeling Cases for both model versions (as demonstrated by Sections 7.7.1.1 and 7.7.1.2 of the parent document and 7.7.1.1[a], and 7.7.1.2[a]), it is reasonable to conclude that the processes affecting radionuclide releases in the Seismic FD Modeling Case are essentially unchanged from TSPA-LA Model v5.000. Because of the similarities in model results, and because TSPA-LA Model v5.000 produces a statistically stable estimate of mean annual dose for the Seismic FD Modeling Case (as demonstrated in Section 7.3.1.2 of the parent document), it is reasonable to conclude that the sample size used in TSPA-LA Model v5.005 produces a statistically stable estimate of mean annual dose for the Seismic FD Modeling Case.

7.3.1.5.8[a]  Total Mean Annual Dose for 20,000 Years

Figure 7.3.1-41[a] shows the distribution of total expected annual dose for 10,000 years and statistics for this distribution for (a) TSPA-LA Model v5.000 and (b) TSPA-LA Model v5.005. The general trends and the range of uncertainty in total expected annual dose are the same for both models. Figure 7.3.1-42[a] shows that the statistics for the distribution of total expected annual dose are similar for both models, and the scatterplots in Figure 7.3.1-43[a] illustrate (at the selected times) that the total expected annual dose is the same for most epistemic sample elements. The similarity in total expected annual dose from both model versions is due primarily to the similarity in expected annual dose from the Seismic GM Modeling Case (Section 7.3.1.5.6[a]) because this case is the dominant contributor to the total expected annual dose in both model versions (compare Figure 8.1-3 of the parent document to Figure 8.1-3[a]). The comparison of Figure K8.1-2a of the parent document and Figure K8.1-2a[a] demonstrates that the uncertain inputs that predominately determine uncertainty in total expected annual dose are the same for both versions. The comparison of Figure 8.1-3a of the parent document and Figure 8.1-3a[a] shows that the contribution of each modeling case to total mean annual dose is unchanged. Finally, Section 7.7.1[a] demonstrates that processes affecting radionuclide releases in each modeling case are essentially unchanged from TSPA-LA Model v5.000. In summary, it is reasonable to conclude that the sample size used in TSPA-LA Model v5.005 produces a statistically stable estimate of total mean annual dose for 20,000 years because (1) model changes are relatively minor, (2) both models use nearly identical LHSs of the same size, (3) model results show close agreement in both the magnitude and range of uncertainty of total expected annual dose, (4) the uncertain inputs that predominately determine uncertainty in total expected annual dose are identical for both versions, (5) the contribution of each modeling case
to total mean annual dose is unchanged, (6) important processes affecting radionuclide releases are unchanged, and (7) TSPA-LA Model v5.000 produces a statistically stable estimate of total mean annual dose (demonstrated in Section 7.3.1 of the parent document).

### 7.3.1.5.9[a] Total Mean Annual Dose for 1,000,000 Years

Figure 7.3.1-44[a] shows the distribution of total expected annual dose for 1,000,000 years and statistics for this distribution for (a) TSPA-LA Model v5.000 and (b) TSPA-LA Model v5.005. Figure 7.3.1-44[a] shows some differences in the general trend in total expected annual dose between the two sets of model results. The comparison of Figure 8.1-3b of the parent document and Figure 8.1-3b[a] shows that the differences in the trends in dose history result from changes that affect the Seismic GM Modeling Case. Specifically, as discussed in Section 7.3.1.5.6[a], improving upon the conservative treatment of synergisms between seismic events and nominal corrosion processes (Appendix P, Section P3, of the parent document) results in changes in total mean annual dose between about 100,000 years and 600,000 years. The range of uncertainty in total expected annual dose is compared for the two sets of model results in Figure 7.3.1-45[a]. Before 600,000 years, the reduction in the magnitude of the mean, median, 5th and 95th percentiles for total expected annual dose is due to the reduction in CSNF WP damage in the Seismic GM Modeling Case in the TSPA-LA Model v5.005. After 600,000 years, the reduction in magnitude of the mean of total expected annual dose is due to the corrected distribution for the longitudinal dispersivity (documented in Section 6.3.10[a] of this addendum), which results in a general reduction in the expected annual dose for the Igneous Intrusion Modeling Case (Section 7.3.1.5.4[a]). However, the range of uncertainty in total expected annual dose is generally the same for the two sets of model results.

Figure 7.3.1-46[a] illustrates (at the selected times) that the total expected annual dose is similar for many epistemic sample elements. Figure 7.3.1-46b[a] shows the reduction in the total expected annual dose at 200,000 years, which was noted in the comparison in the uncertainty in the total expected annual dose discussed above. The comparison of Figure K8.2-2a and Figure K8.2-2a[a] demonstrates that the uncertain inputs that predominantly determine uncertainty in total expected annual dose after 10,000 years are the same for both versions. Finally, Section 7.7.1[a] demonstrates that processes affecting radionuclide releases in each modeling case are essentially unchanged from TSPA-LA Model v5.000.

In summary, although there are significant differences in the total expected annual dose between approximately 100,000 to 300,000 years, the important processes affecting radionuclide releases remain unchanged, and (1) model changes to the TSPA-LA Model v5.005 are relatively minor, (2) both models use nearly identical LHSs of the same size, (3) the uncertain inputs that predominantly determine uncertainty in total expected annual dose are the same for both versions, (4) model results are similar in both the magnitude and range of uncertainty of total expected annual dose over the majority of the simulation, and (5) the relative contributions of each modeling case to total mean annual dose is unchanged. Since the TSPA-LA Model v5.000 produces a statistically stable estimate of total mean annual dose (demonstrated in Section 7.3.1 of the parent document), it is reasonable to conclude that the sample size used in TSPA-LA Model v5.005 produces a statistically stable estimate of total mean annual dose for 1,000,000 years.
7.3.1.6[a] Procedure for Computing Confidence Intervals

To provide a quantitative assessment of the accuracy of the estimate of total mean annual dose for TSPA-LA Model v5.005, a bootstrap sampling procedure is used to generate confidence intervals. Bootstrap simulation is a numerical procedure for estimating confidence intervals for statistics of interest. Given a sample of size $n$, the general approach in bootstrap simulation is to: (1) assume that the sample is an adequate approximation of the underlying distribution; (2) perform $r$ replications of the set of values by randomly selecting, with replacement, $n$ values from the sample; and (3) calculate $r$ values for the statistic of interest. Davison and Kuonen (2002 [DIRS 184463]) provide an outline of the bootstrap procedure. The underlying assumption that the sample is an adequate approximation of the underlying distribution is justified because (1) the assumption has already been justified for TSPA-LA Model v5.000, as demonstrated by the stability analysis presented in Section 7.3.1 of the parent document; (2) TSPA-LA Model v5.005 produces results with uncertainty ranges similar to those observed for the TSPA-LA Model v5.000 results; and (3) uncertain inputs that dominate uncertainty in total expected annual dose are generally the same for TSPA-LA Model v5.000 and TSPA-LA Model v5.005.

Figure 7.3.1-47[a] displays the confidence interval for total mean annual dose for a simulation of 20,000 years, computed by using the bootstrap technique for both versions of the TSPA-LA Model. The upper and lower confidence bounds displayed on Figure 7.3.1-47[a] are the 97.5 percentile and 2.5 percentile, respectively, for the sampling distribution of total mean annual dose. Figure 7.3.1-47[a] shows that, with a probability 0.975, the true mean is estimated to lie more than an order of magnitude below the individual protection standard of 15 mrem for 10,000 years after permanent closure as specified in 10 CFR 63.311(a)(1) [DIRS 178394]. The narrowness of the confidence interval (less than ±0.2 mrem/yr) over the 20,000-year simulation and the relatively large separation between the confidence interval and the regulatory limit relative to the width of the confidence interval indicates that total mean annual dose for this modeling case is estimated with sufficient accuracy. The corresponding confidence interval for TSPA-LA Model v5.000 (Replicate 1) is shown for comparison.

Figure 7.3.1-48[a] shows the confidence interval for total mean annual dose for 1,000,000 years. Again, the upper and lower confidence bounds displayed on Figure 7.3.1-48[a] are the 97.5 percentile and 2.5 percentile, respectively, for the sampling distribution of total mean annual dose. Similar to the 20,000-year simulation, the narrowness of the confidence interval (less than ±0.5 mrem/yr) over the 1,000,000-year simulation and the separation between the confidence interval and the regulatory standard of 350 mrem specified in U.S. Nuclear Regulatory Commission Proposed Rule 10 CFR 63.311(a)(2) [DIRS 178394]) indicates that total mean annual dose for this modeling case is estimated with sufficient accuracy.

7.3.1.7[a] Conclusion

In Section 7.3.1 of the parent document, statistical stability of the total mean annual dose was evaluated by means of a replicated sampling procedure. The comparison of three estimates of total mean annual dose and the associated distributions of uncertainty in expected annual dose showed that the three independent LHS replicates produced statistically similar values of the total mean annual dose, as well as similar distributions of uncertainty in expected annual dose. The analysis concluded that the results of TSPA-LA Model v5.000 are statistically stable.
Statistical stability of the total mean annual dose presented in this addendum was evaluated by means of comparisons between TSPA-LA Model v5.000 and TSPA-LA Model v5.005 and results from these models, for all except the Human Intrusion Modeling Case. The relatively few changes between the models, and the similarities evident in the results of the models, support the conclusion that because the results of TSPA-LA Model v5.000 are demonstrated to be statistically stable, the results of TSPA-LA Model v5.005 are also statistically stable. Confidence intervals are computed for TSPA-LA Model v5.005 using a bootstrap procedure. The replicated sampling procedure was repeated for the Human Intrusion Modeling Case to demonstrate statistical stability.
Table 7.3.1-1[a]. Uncertainty Distribution Changes for TSPA-LA Model v5.005

<table>
<thead>
<tr>
<th>Parameter Listing (Table K3-2)</th>
<th>TSPA-LA Model Description</th>
<th>TSPA-LA Model v5.000</th>
<th>TSPA-LA Model v5.005</th>
</tr>
</thead>
<tbody>
<tr>
<td>LDISP</td>
<td>Section 6.3.10.2, Section 6.3.10.2[a], Table 6.3.10-2</td>
<td>Normal: (Log_{10}-transformed) Mean: 2.0 m Standard Deviation: 0.75 m</td>
<td>Truncated Normal: (Log_{10}-transformed) Mean: 2.0 m Standard Deviation: 0.75 m Maximum 2 Standard Deviation</td>
</tr>
<tr>
<td>FHH_Isotherm_k_CP_a</td>
<td>Table 6.3.8-4[a], Table P-6, 7</td>
<td>Uniform (1.048 to 1.370)</td>
<td>Uniform (1.030 to 1.326)</td>
</tr>
<tr>
<td>FHH_Isotherm_s_CP_a</td>
<td>Table 6.3.8-4[a], Table P-6, 7</td>
<td>Uniform (1.525 to 1.852)</td>
<td>Uniform (1.493 to 1.799)</td>
</tr>
<tr>
<td>KdU_Zeo_a</td>
<td>Section 6.3.9.2, Section 6.3.9.3, Table 6.3.9-2, Table P-6, 11</td>
<td>Piecewise Uniform (0 to 20 mL/g)</td>
<td>Piecewise Uniform (0 to 30 mL/g)</td>
</tr>
<tr>
<td>KdSe_Vit_a</td>
<td>Section 6.3.9.2, Section 6.3.9.3, Table 6.3.9-2, Table P-6, 10</td>
<td>Truncated log normal (1 to 25 mL/g)</td>
<td>Truncated lognormal (0 to 25 mL/g)</td>
</tr>
<tr>
<td>Kd_Np_Rev_U_Col_a</td>
<td>Section 6.3.7.6.2, Section 6.3.7.6.3, Table 6.3.7-64, Table 6.3.7-64[a], Table P-6, 8</td>
<td>Log Uniform (1 to 500 mL/g)</td>
<td>Log Uniform (10 to 500 mL/g)</td>
</tr>
</tbody>
</table>
INTENTIONALLY LEFT BLANK
7.3.2[a] Numerical Accuracy of Expected Annual Dose
No change.

7.3.2.1[a] Nominal Modeling Case
No change.

7.3.2.2[a] Waste Package Early Failure Modeling Case
No change.

7.3.2.3[a] Drip Shield Early Failure Modeling Case
No change.

7.3.2.4[a] Igneous Intrusion Modeling Case
No change.

7.3.2.5[a] Volcanic Eruption Modeling Case
No change.

7.3.2.6[a] Seismic Ground Motion Modeling Case
No change.

7.3.2.6.1[a] Seismic Ground Motion Modeling Case for 10,000 Years
No change.

7.3.2.6.1.1[a] Accuracy of Expected Annual Dose Calculations
No change.

7.3.2.6.1.2[a] Additivity in Annual Dose from Multiple Seismic Events
This section has been edited for clarity and replaces the corresponding section in the parent document.

As noted in Section 6.1.2.4.4 of the parent document, Equation 6.1.2-22 is based on the assumption that the annual dose from two or more events causing cumulative damage to WPs is reasonably approximated by the sum of the annual doses from the events modeled independently. Figure 7.3.2-12 of the parent document illustrates the change in annual dose at 10,000 years due to changes in damage fraction, after an event at 100 years, for epistemic realization 1. The change in annual dose is proportional to changes in damage fraction up to the damage fraction of about $10^{-5}$. Beyond the damage fraction of $10^{-5}$, annual dose does not increase proportionally with increasing damage fraction. Thus, when two or more seismic events cause cumulative damage fraction exceeding $10^{-5}$, the additivity assumption results in an overestimate of the annual dose resulting from seismic events. The dose resulting from a single event causing
damage fraction exceeding $10^{-5}$ is not overestimated since this quantity is computed by interpolation between the level curves shown on Figure 7.3.2-9 of the parent document.

To estimate the degree of conservatism incurred by this additivity assumption, expected annual dose from one seismic event was calculated by evaluating the first integral term in Equation 6.1.2-22:

$$
D_{SG} \left( \tau, \mathbf{e}_i \right) = \int_0^\tau \left[ \lambda_i (\mathbf{e}_i) e^{-\lambda_i (\mathbf{e}_i) t} \int_{A_{max}}^\infty D_{SG} \left( \tau, \mathbf{t}, \mathbf{A} \right) \lambda (\mathbf{A} \mathbf{e}_i) dA \right] dt \quad \text{(Eq. 7.3.2-1[a])}
$$

The integral displayed in Equation 7.3.2-1[a] computes the expected annual dose from the first seismic event that damages co-disposed (CDSP) WPs. The second integral in Equation 6.1.2-22 computes the additional expected annual dose from the second and subsequent seismic events. Figure 7.3.2-13 of the parent document shows the expected annual dose from the first damaging seismic event; Figure 7.3.2-14 of the parent document shows the expected annual dose from all damaging seismic events for all 300 epistemic realizations. The comparison of the expected annual dose from the first damaging event to the expected annual dose from all damaging events shows that the second and subsequent damaging events add somewhat to the magnitude of the expected annual dose but do not change the magnitude or range of uncertainty to any great extent. Consequently, the additivity assumption, while conservative, does not result in a significant overestimate of the expected annual dose.

7.3.2.6.1.3[a]  Simplifications to the Seismic Consequences Abstraction

No change.

7.3.2.6.2[a]  Seismic Ground Motion Modeling Case for 1,000,000 Years

No change.

7.3.2.7[a]  Seismic Fault Displacement Modeling Case

The analysis presented in the parent document showed the expected annual dose for the Seismic Fault Displacement Modeling Case is estimated with sufficient accuracy. However, the analysis showed the calculation’s accuracy could be improved by further discretization of the aleatory variables. In particular, Figure 7.3.2-26 (of the parent document) compares the expected annual dose for five epistemic realizations for a base case of aleatory discretization and an expanded case; the expected annual dose generally increased by approximately 30 percent in the expanded case. To determine whether further refinement in aleatory discretization would lead to additional increases in expected annual dose, a second expanded case was formed and expected annual dose was evaluated. In this second expansion case the number of times of fault displacement events was increased from 6 to 23 and the number of damage areas was again increased from 3 to 5. The results did not show further increase in expected annual dose (output DTN: MO0801TSPAADSA.000 [DIRS 185078], file LA_v5.000_SF_010800_10k_Dose_Compare_Rev01.JNB), confirming the assessment that expected annual dose is computed with sufficient numerical accuracy.
7.3.2.8[a] Human Intrusion Modeling Case
No change.

7.3.3[a] Temporal Stability
This material supplements the corresponding section in the parent document.

Another issue related to the stability of the TSPA-LA Model results is temporal discretization of the model. In order to calculate transport of radionuclides, the TSPA-LA Model numerically solves partial differential equations in various submodels (e.g., FEHM for UZ transport) and model abstractions (e.g., SZ 3-D transport). The numerical solution involves computations with discrete timesteps which is referred to as temporal discretization. Temporal discretization may affect the accuracy of the solution of the differential equations and, thereby, affect the results of the TSPA-LA Model. Several different TSPA-LA Model runs were documented in Section 7.3.3 of the parent document that evaluated the potential for variability in model output due to timestep size. These analyses demonstrated that the output of the TSPA-LA Model is not significantly affected by refining the temporal discretization and concluded that the temporal discretization used in the TSPA-LA Model is adequate. Included in Section 7.3.3.6[a] of this addendum is an update to the temporal stability for the Human Intrusion Modeling Case necessitated by the correction of an error documented in Appendix P, Table P-6, Item 6, of the parent document. In addition, a temporal stability assessment of the Nominal Modeling Case has been added as Section 7.3.3.7[a] of this addendum.

7.3.3.1[a] Selection of Modeling Cases
No change.

7.3.3.2[a] Methodology
No change.

7.3.3.3[a] Waste Package Early Failure Modeling Case
No change.

7.3.3.4[a] Igneous Intrusion Modeling Case
No change.

7.3.3.5[a] Seismic Ground Motion Modeling Case
No change.

7.3.3.6[a] Human Intrusion Modeling Case
In the Human Intrusion Modeling Case, a single stylized intrusion occurs at 200,000 years. Annual dose is computed by the GoldSim component of the TSPA-LA Model for each combination of a sampled intrusion location (characterized by WP type, percolation rate and entry point into the SZ) and epistemic realization. For each epistemic realization, the ensemble
of dose histories is averaged to compute expected dose, as described by Equation 6.1.2-26 in Section 6.1.2.5 of the parent document. At the time of the intrusion, percolation begins to flow through the waste and transport the radionuclides down the borehole to the SZ. Thus, the dose following an intrusion has a large initial value that decreases rapidly as radionuclide inventory is depleted or decays.

To complete a comprehensive analysis of temporal stability for the TSPA-LA Model, an additional analysis is presented in this addendum for the Human Intrusion Scenario, which includes the correction of a timestep error documented in Appendix P, Table P-6, Item 6, of the parent document. In the parent document, temporal stability for the Human Intrusion Modeling Case was judged to be adequate, despite the presence of the timestep error and the coarseness of the temporal resolution of expected dose (see Figures 7.3.3-10 and 7.3.3-11 of the parent report). Because of the correction of the timestep error and the coarseness evident in the parent document, the base timestep scheme for the Human Intrusion Modeling Case was revised to that shown in Table 7.3.3-2[a], and temporal stability was re-assessed for TSPA-LA Model v5.005. Figure 7.3.3-10[a] compares the base-case timestep results with the alternative timestep scheme for the 1,000,000 Year simulation period. Figure 7.3.3-11[a] focuses on the dose immediately after the intrusion (out to 220,000 years only) and shows that the base-case timestep size in TSPA-LA Model v5.005 provides results that are nearly identical to the alternate timestep scheme. The similarity in expected annual dose for the two timestep schemes confirms that the Human Intrusion Modeling Case is stable with respect to temporal discretization.

7.3.3.7[a]  Nominal Modeling Case

The Nominal Modeling Case estimates the annual dose resulting from WP failures from nominal corrosion processes (i.e., general corrosion, microbial influenced corrosion, stress corrosion cracking [SCC]), as well as the effects of general corrosion of DS materials (Section 6.3.5 of the parent document). The number and type of WP failures at each point in time is estimated by the use of several software packages, as described in Section 6.3.5.1.3 of the parent document; the radionuclide transport and dose resulting from this sequence of failures is estimated by the GoldSim component of the TSPA-LA Model, as described in Section 6.1.2.4.1 of the parent document.

The time of failure of a WP depends on the temperature-dependent general corrosion rates applied to the WP, which change over time as temperature changes. Thus, the temporal discretization, which defines when the value of the general corrosion rate will be updated, is influential to the annual dose resulting from nominal corrosion processes.

In the base case, the coarse timestep discretization beyond 200,000 years used to calculate general corrosion was taken from the thermal hydrology histories. The temperature and relative humidity data did not fluctuate significantly once ambient conditions within the repository were reestablished and a coarse timestep discretization was selected to represent the data. The general corrosion calculations used the same timestep discretization. In the temporal stability study, the timestep discretization used by the general corrosion calculations was refined by updating the timestep scheme in the thermal hydrology history files. The number of data points was increased from 68 in the base case to 279 in the temporal stability run. The timesteps for the base case are found in the files with an .ou extension within output DTN: MO0710ADTSPAWO.000
The GoldSim timestep schedule was not altered for this analysis. The new timestep discretization was selected so that the maximum timestep size used in the general corrosion calculations was 10,000 years. The timestep schedule maintained the timestep scheme previously used for the first 750 years. From 200 years up until 1000 years, the timestep size was 50 years. From 1,000 years to 10,000 years the timestep size was 100 years, compared to a maximum 2,000 year timestep over this time period in the base case. From 10,000 years to 20,000 years the timestep size was 500 years, compared to a maximum 5,000 year timestep over this time period in the base case. From 20,000 years to 50,000 years the timestep size was 1000 years, compared to a maximum 10,000 year timestep over this time period in the base case. From 50,000 years to 75,000 years the timestep size was 2500 years, compared to a maximum 20,000 year timestep over this time period in the base case. From 75,000 years to 100,000 years the timestep size was 5000 years, compared to a maximum 30,000 year timestep over this time period in the base case. Beyond 100,000 years the timestep size was 10,000 years until the last time point at 999,950 years, compared to a maximum 300,000 year timestep over this time period in the base case.

Figure 7.3.3-12[a] compares the base-case timestep results with the alternative timestep scheme for the 1,000,000 year simulation period. The few realizations with expected annual dose before 200,000 years appear similar for either timestep scheme. However, in the base case, the coarse timesteps used after 200,000 years result in observable jumps in expected annual dose at 200,000; 300,000; 500,000 and 700,000 years. At these timesteps, the number of WP failures (from SCC) calculated by the WP degradation code WAPDEG V4.07 (STN: 10000-4.07-01 [DIRS 181064]) increases sharply. The stress corrosion crack growth rate is given by a power law function of stress intensity factor and repassivation slope n (Equation 6.3.5-14 of the parent document). The stress intensity factor is evaluated at the beginning of each WAPDEG timestep and is a function of the crack depth that drives the crack propagation. The large timesteps taken past 100,000 years combined with the sensitivity of the crack growth rate to the stress intensity factor, which is raised to the power 4n, where n has a mean value of 1.165 (SNL 2007 [DIRS 181953], Table 8-15), can cause dramatic changes in the crack growth rate at each timestep. As a result, the crack growth rate can change from a small value for the timestep in which the crack initiates to a much larger value at the beginning of the next timestep, resulting in almost immediate penetration of many cracks and WP failures. Use of shorter timesteps in the alternative scheme improves the calculation of the crack growth rate, which removes the jumps in the number of WP failures by SCC, which in turn is reflected in the expected annual dose curves for the alternative scheme. The increase in expected annual dose from using the increased number of timesteps in the alternative time scheme is due to an increase in the number of WP failures calculated by the WAPDEG code. Between the two cases, the number of WP failures were approximately the same midway between each large timestep used in the base case (output DTN: MO0801TSPAWPDS.000 [DIRS 185077], file: LA_v5.005_NC_000300_006_Dose_Assessment.doc), but the base case underestimated the number of WP failures in the second half of the WAPDEG timestep. The WAPDEG code applies an average penetration depth over an entire timestep to determine the general corrosion and stress corrosion consequences for each timestep. Applied as an average, the calculated results for a large timestep are overestimated in the beginning of the timestep and underestimated at the end of the timestep. Thus, because the TSPA-LA Model ends at the end of a WAPDEG timestep, the number of failures is underestimated at the end of the realization.
Figure 7.3.3-13[a] compares statistics on expected annual dose for the base-case and the alternative timestep scheme. The comparison shows that both the magnitude of expected annual dose and the range of uncertainty in expected annual dose are similar for both timestep schemes. This similarity in statistics for expected annual dose for the two timestep schemes indicates that the Nominal Modeling Case is sufficiently stable with respect to temporal discretization and that any underestimation in dose due to the large WAPDEG timesteps taken in the base case is not significant.

The timestep scheme for the base case model was selected for computational efficiency. In the base case calculations, the WAPDEG calculations accounted for about 40 to 50 percent of the simulation time. In the sensitivity study, the WAPDEG calculation time increased by a factor of four, doubling the run time. Because the TSPA-LA Model results were judged to be sufficiently stable with respect to temporal discretization and because improving the smoothness of the expected annual dose curves would involve significant additional calculation time, the base case timestep scheme was used in the TSPA-LA Model for the Nominal Modeling Case.
### Table 7.3.3-2[a]. Revised Timestep Schemes used in Temporal Stability Analysis

<table>
<thead>
<tr>
<th>Modeling Case</th>
<th>Base-Case Timestep Scheme (v5.000)</th>
<th>Base-Case Timestep Scheme (v5.005)</th>
<th>First Alternate Timestep Scheme</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human Intrusion (intrusion occurs at 200,000 yr)</td>
<td>250 yr from 0 to 10k yr 500 yr from 10k to 100k yr 1,000 yr from 100k to 120k yr 2,000 yr from 120k to 160k yr 4,000 yr from 160k to 1M yr</td>
<td>250 yr from 0 to 10k yr 500 yr from 10k to 100k yr 1,000 yr from 100k to 120k yr 2,000 yr from 120k to 158k yr 4,000 yr from 158k to 198k yr 250 yr from 198k to 204k yr 1,000 yr from 204k to 212k yr 4,000 yr from 212k to 1M yr</td>
<td>250 yr from 0 to 10k yr 500 yr from 10k to 100k yr 1,000 yr from 100k to 120k yr 2,000 yr from 120k to 158k yr 4,000 yr from 158k to 198k yr 40 yr from 198k to 204k yr 400 yr from 204k to 212k yr 4,000 yr from 212k to 1M yr</td>
</tr>
</tbody>
</table>

Source: Output DTNs: MO0709TSPAREGS.000 [DIRS 182976], File: V5.000_HI_009000_002.gsm (for Base Case v5.000); MO0710ADTSPAWO.000 [DIRS 183752], File: v5.005_HI_009000_000.gsm, (for Base Case v5.005); and MO0801TSPAADSA.000 [DIRS 185078], File: v5.005_HI_009000_001.gsm, (for Alternate).
7.3.4[a] Analyses of Spatial Discretization

No change.

7.3.5[a] Stability of FEHM Particle Tracking Model

No change.

7.4[a] UNCERTAINTY AND VARIABILITY CHARACTERIZATION REVIEWS

No change.

7.5[a] SURROGATE WASTE FORM VALIDATION

This material supplements the corresponding material in the parent document.

The purpose of the analyses documented in Section 7.5 of the parent document is to show that the surrogate representation of naval spent fuel (Category 1 DOE spent nuclear fuel [DSNF]) and the DSNF surrogate, the average of DSNF Categories 2 through 11, are appropriate. The averaging of Categories 2 through 11 is related to the spatial averaging that is analyzed in Section 7.3.4 of the parent document.

The updated analyses presented in this addendum were conducted to confirm that Zircaloy-clad CSNF adequately represents Category 1 DSNF in TSPA-LA Model v5.005. Category 1 DSNF, naval spent fuel in the TSPA-LA Model, is represented as Zircaloy-clad CSNF. Section 7.5.3[a] discusses the analyses using TSPA-LA Model v5.005 where the naval source term replaced the CSNF source term for the Drip Shield EF and Igneous Intrusion Modeling Cases.

7.5.1[a] Methodology

No change.

7.5.2[a] Spent Fuel Categories and Representation in Model

No change.

7.5.3[a] Naval Spent Fuel, Category 1

Analyses were performed to confirm the adequacy of the use of CSNF as a surrogate for NSNF. These analyses are outlined in Table 7.5-5 of the parent document. The analyses were conducted for simulations of 10,000 years, and a qualitative argument for the extension of the results beyond 10,000 years is also presented. For this addendum, TSPA-LA Model v5.005 was exercised explicitly using NSNF inventories in place of the CSNF inventory. The dose results from these cases were compared to demonstrate that CSNF inventory bounds the NSNF inventory.
7.5.3.1[a] Comparison of the Naval Spent Nuclear Fuel and Commercial Spent Nuclear Fuel Inventories for 10,000 Years and 1,000,000 Years

No change.

7.5.3.2[a] Disposition of Commercial Spent Nuclear Fuel as a Surrogate for Naval Spent Nuclear Fuel for the Early Failure Modeling Cases

NSNF was analyzed using inventories, or source terms, supplied by the Navy for radionuclides that are available for release from naval spent fuel. The source terms are based on a hypothetically failed WP of naval spent fuel for the Drip Shield EF and Igneous Intrusion Modeling Cases. These source terms were provided by the Naval Nuclear Propulsion Program (McKenzie 2007 [DIRS 182657]). The analyses of naval spent fuel are special cases developed to compare CSNF and naval spent fuel for the Drip Shield EF and Igneous Intrusion Modeling Cases. For these analyses, the NSNF source term (radionuclides available for release within a failed WP) was modeled in a failed CSNF WP, and the radionuclides were then subject to all of the transport processes that are applied to dissolved CSNF (e.g., solubility, sorption, and chemistry along the transport pathway from dissolved CSNF to the reasonably maximally exposed individual [RMEI]) in the TSPA-LA Model.

In the modeled repository, there are 8,213 WPs of CSNF, 417 of which represent naval spent fuel (SNL 2007 [DIRS 180472], Table 6-2[a]). The TSPA-LA Model does not explicitly include naval spent fuel but bounds its behavior with 417 CSNF WPs that represent naval spent fuel. The special case analyses in this section were conducted to demonstrate that the annual dose from naval spent fuel is bounded by the annual dose from CSNF.

For the validation of CSNF as a surrogate for naval spent fuel for the non-disruptive event cases, the Drip Shield EF Modeling Case was chosen over the Waste Package EF Modeling Case because of the following considerations. First, the transport of radionuclides within the EBS for the Drip Shield EF Modeling Case is advection dominated with some diffusion. The transport of radionuclides within the EBS for the Waste Package EF Modeling Case is diffusion dominated since the drip shield (DS) stays intact. The Waste Package EF Modeling Case would produce lower radionuclide doses compared to the Drip Shield EF Modeling Case and, therefore, can be considered a subset of the Drip Shield EF Modeling Case for the NSNF analysis. In addition, in the TSPA-LA Model, the Waste Package EF Modeling Case applies not only a temperature threshold to transport, but a relative humidity threshold to transport radionuclides from the waste form to the WP OCB. Since the naval source term is a release from a failed WP, it is implemented in the TSPA-LA Model by applying the release to the WP transport cell and, therefore, bypasses the relative humidity threshold for transport from the waste form transport cell. The result of using the Waste Package EF Modeling Case for the analysis would be an early release of radionuclides to the accessible environment for the naval source term, which would be inconsistent with a later release of radionuclides for the CSNF source term. The delay in release from the waste form to the WP OCB due to the relative humidity threshold for transport is not implemented in the Drip Shield EF Modeling Case. Therefore, for the Drip Shield EF Modeling Case, the timing of the release of radionuclides to the accessible environment from a failed WP with a CSNF source term is more consistent with the timing of the release from a failed WP where the naval source term has been substituted for the CSNF source term in the WP transport cell.
For the Drip Shield EF Modeling Case, a single DS failure was forced to occur at the first timestep of the simulation. Two simulations using TSPA-LA Model v5.005 were run: one for a single CSNF WP and one for a single WP where the naval source term replaced the CSNF source term. The simulations were run for 10,000 years and used a unified sampling of epistemic and aleatory uncertainty over 300 model realizations. The results, in terms of a mean annual dose over the unified sampling of epistemic and aleatory uncertainty, are shown on Figure 7.5-4[a]. As noted in the results documented in the parent document, the results of this analysis show that over a 10,000-year period, the dose associated with the naval source term is less than that of the CSNF source term. At 10,000 years, the mean annual dose from a failed WP with a naval source term is over two orders of magnitude lower than the mean annual dose for a failed CSNF WP, confirming the appropriateness of the use of a CSNF WP as a surrogate for a naval WP.

7.5.3.3[a] Disposition of Commercial Spent Nuclear Fuel as a Surrogate for Naval Spent Nuclear Fuel for the Igneous Intrusion Modeling Case

A similar analysis conducted for the Igneous Intrusion Modeling Case is used to confirm the appropriateness of the use of CSNF as a surrogate for NSNF. For both the CSNF and naval source term stylized analysis, the time of the igneous intrusion was forced to occur at a specified timestep, and a single WP was failed. Using TSPA-LA Model v5.005, simulations were run for 10,000 years and used a unified sampling of epistemic and aleatory uncertainty over 300 model realizations. The results, in terms of a mean annual dose over the unified sampling of epistemic and aleatory uncertainty, are shown on Figure 7.5-5[a]. As was the case for the Drip Shield EF Modeling Case, the results for the Igneous Intrusion Modeling Case show that for a 10,000-year period, the dose associated with the naval source term is less than that of the CSNF source term, again justifying the use of a CSNF WP as a surrogate for a naval WP.

7.5.3.4[a] Disposition of Commercial Spent Nuclear Fuel as a Surrogate for Naval Spent Nuclear Fuel for the Volcanic Eruption Modeling Case

No change.

7.5.3.5[a] Disposition of Commercial Spent Nuclear Fuel as a Surrogate for Naval Spent Nuclear Fuel for the Human Intrusion Modeling Case

No change.

7.5.3.6[a] Disposition of Commercial Spent Nuclear Fuel as a Surrogate for Naval Spent Nuclear Fuel for the Nominal Modeling Case

Note, minor reference change from the parent document.

The use of CSNF as a surrogate for NSNF for the first 10,000 years of the Nominal Modeling Case is justified because there are no WP failures during this time period, and because the naval WP is more robust than the commercial WP. The 1,000,000 year Nominal Modeling Case is a stylized case (see Section 8.2.1 of the parent document) where the WP fails by SCC and general corrosion sometime after the first 10,000 years. These effects are accounted for in the 1,000,000 year Seismic GM Modeling Case. The use of CSNF as a surrogate for NSNF for the 1,000,000 year Nominal Modeling Case is justified because of the NSNF is adequately represented by
CSNF in the early failure cases, and again because the naval WP is more robust than the commercial WP.

7.5.3.7[a] Disposition of Commercial Spent Nuclear Fuel as a Surrogate for Naval Spent Nuclear Fuel for the Seismic Modeling Cases.

No change.

7.5.4[a] U.S. Department of Energy Spent Fuel, Categories 2 through 11

No change.

7.5.5[a] Selected Sensitivity Analyses

No change.

7.5.6[a] Summary of Results for U.S. Department of Energy Spent Fuel

The additional analyses presented in this section of the addendum confirm that comparing naval spent fuel with Zircaloy-clad CSNF demonstrates that CSNF bounds the results of naval spent fuel for both non-disruptive (Drip Shield EF) and disruptive event (Igneous Intrusion) modeling cases. Additional analyses performed by the Naval Nuclear Propulsion Project as documented in Section 7.5.3.7 of the parent document confirm the use of CSNF as a surrogate for naval spent fuel for the seismic scenarios (Gisch 2004 [DIRS 171782]). Representing naval spent fuel by CSNF as its surrogate in the TSPA-LA Model adequately bounds the behavior of naval spent fuel (Section 7.5.3[a]).

No additional analyses were conducted for the remaining categories of DSNF.

7.6[a] CORROBORATION OF ABSTRACTION MODEL RESULTS WITH VALIDATED PROCESS MODELS

No change.

7.7[a] CORROBORATION OF RESULTS WITH AUXILIARY ANALYSES

The auxiliary analyses are an important aspect of determining whether the TSPA-LA Model is yielding reasonable results (e.g., that the model is producing the results that would be expected). To supplement the results presented in Section 7.7 of the parent document, the following auxiliary analyses were performed using TSPA-LA Model v5.005 and documented in this addendum: (1) single realization analysis of various modeling cases, including additional analyses for outlier realizations; (2) comparison of the results of the TSPA-LA Model with a Simplified TSPA Analysis (Section 7.7.2[a]); (3) comparison of the results of the TSPA-LA Model with the TSPA independently developed by EPRI (Section 7.7.3[a]); and (4) PMA (Section 7.7.4[a]). A summary of the additional auxiliary analyses included in this addendum is provided below.
Analyses of Single Realizations

Analyses of single realizations provide insight into the coupling of various submodel processes within the TSPA-LA Model. The analyses presented in Section 7.7.1 of the parent document and Section 7.7.1[a] of this addendum include an in-depth explanation about how the transport of key radionuclides is affected by coupling various components of the EBS, UZ, and SZ domains following WP failure under a variety of physical, chemical, thermal, and mechanical conditions. The insight gained provides assurance that the various submodel processes are working as expected and, in turn, helps provide confidence in the TSPA-LA Model.

The single realization analyses presented in this addendum evaluate seven modeling cases that are used to cover the range of WP failure mechanisms considered in the TSPA-LA Model and highlight various processes affecting and controlling radionuclide releases under a variety of conditions. The seven modeling cases are: (1) Waste Package EF Modeling Case (Section 7.7.1.1[a]), (2) Drip Shield EF Modeling Case (Section 7.7.1.2[a]), (3) Igneous Intrusion Modeling Case (Section 7.7.1.3[a]), (4) Seismic GM Modeling Case (Section 7.7.1.4[a]), (5) Nominal Modeling Case (Section 7.7.1.5[a]), (6) Human Intrusion Modeling Case (Section 7.7.1.6[a]), and (7) Seismic GM Modeling Case for the 10,000-year duration (Section 7.7.1.7[a]). The durations for all modeling cases, except where noted, was 1,000,000-years.

The methodology for calculating expected annual dose (i.e., the expectation of annual dose over aleatory uncertainty) for the various modeling cases is described in Section 6.1.2 of the parent document, which discusses how to differentiate epistemic uncertainty from aleatory uncertainty in the TSPA-LA Model. Although the treatment of aleatory uncertainty varies with each modeling case, the general methodology for selecting a realization for detailed analysis is similar for all seven modeling cases described in this section. First, an epistemic uncertainty vector is chosen from the set of epistemic uncertainty vectors. The two primary criteria for selecting a particular epistemic uncertainty vector are that (1) the functional form (shape) of the expected annual dose (for the chosen epistemic vector) is similar to that of the mean annual dose (computed by taking expectation over all epistemic uncertainty vectors) and (2) the magnitude of the expected annual dose for the chosen epistemic vector is similar or higher than the mean annual dose over the time period of interest. These criteria are intended to help select epistemic uncertainty vectors that highlight processes of most interest for each modeling case. Since the expected annual dose for an epistemic vector is calculated by taking the expectation over aleatory uncertainty, each expected annual dose is further broken down in order to select the realization(s) representing individual aleatory uncertainty vectors. An aleatory vector is chosen by comparing its dose contribution to other aleatory vectors in the set and that which best describes the behavior of the expected annual dose for the epistemic vector over the time period of interest. For the Igneous Intrusion, Human Intrusion, Nominal, and the two Seismic GM Modeling Cases, one GoldSim realization, representing a unique combination of epistemic and aleatory uncertainties, is chosen for detailed analyses. For the Waste Package EF and Drip Shield EF Modeling Cases, two GoldSim realizations, representing two aleatory uncertainty vectors (corresponding to CSNF and CDSP WP locations) for a given epistemic uncertainty vector, are selected to adequately describe the expected annual dose for the chosen epistemic uncertainty vector. More details about how a specific single realization was selected for analysis are presented in each subsection.
In addition to the detailed explanation of results from the chosen realization (representing a typical epistemic and aleatory vector), an outlier realization is analyzed for selected modeling cases. The realization is chosen in such a way that the expected dose is one of the highest for the period of interest. The motivation for analyzing an outlier realization is to understand the combination of parameters or submodels that lead to the large expected dose, because the mean annual dose is influenced more by an outlier realization than by any other realization.

The analysis for the outlier realization is limited to highlighting the primary reasons for its high dose and contrasting them to the results presented for the typical realization. The outlier realization analysis for a given modeling case is presented at the end of the section where the detailed single realization analysis for the same modeling case is described. The outlier realization analysis is conducted for all modeling cases except for the two Seismic GM Modeling Cases because the epistemic vector chosen for the detailed analysis in the two Seismic GM Modeling Cases also has large expected dose.

All single realization analyses discussed below are carried out by running the single realizations using GoldSim software (GoldSim v9.60.300, STN: 10344 9.60-03 [DIRS 184387]). However, the results of the expected annual doses are based on calculations performed by using EXDOC_LA software (EXDOC_LA V2.0, STN: 11193-2.0-00 [DIRS 182102]) with proper weighting of scenario-specific probabilities and expectations over aleatory and epistemic uncertainties.

7.7.1.1[a] Waste Package Early Failure Modeling Case

This section presents analyses of two realizations selected from the 6,000 realization base-case run performed for calculating expected annual dose from the Waste Package EF Modeling Case (GoldSim filename: LA_v5.005_EW_006000_000.gsm; output DTN: MO0710ADTSPAWO.000 [DIRS 183752]). The distribution of expected annual dose, along with the mean and various quantiles, is shown on a linear time scale (Figure 7.7.1-1[a]) and on a log-time scale (Figure 7.7.1-1b[a]), the latter to more clearly illustrate the variation in dose at early times. The 300 displayed expected annual dose histories correspond to 300 epistemic uncertainty vectors. Each expected annual dose history is calculated as a weighted average of twenty aleatory uncertainty vectors (Equation 6.1.2-13 of the parent document). The twenty aleatory uncertainties are derived by considering the five spatial percolation subregions, two environments (seeping and non-seeping environments) for each percolation subregion, and two WP types for each environment (Section 6.1.2.4 of the parent document). Early failure of one WP is modeled for each of the aleatory vectors. Epistemic vector 281 is chosen for detailed analysis since it has an expected annual dose curve similar to the mean (Figure 7.7.1-1[a]). The twenty aleatory uncertainty vectors corresponding to epistemic vector 281 are GoldSim realization numbers 5601 through 5620 (Figure 7.7.1-2[a]).

The mean annual dose from this modeling case has several peaks (Figure 7.7.1-1b[a]). The first broad peak between 1,000 and 10,000 years is due to contributions from CDSP WPs, predominantly, as the relative humidity in the CDSP WPs in the various percolation subregions exceeds 95 percent and diffusive transport begins (Section 5.1.4 of the parent document). A second set of dose peaks between 10,000 and 30,000 years reflects dose contributions from CSNF WPs when the relative humidity inside CSNF WPs in the various percolation subregions
Total System Performance Assessment Model/Analysis for the License Application

rises above 95 percent. The last broad dose peak occurs after the DSs fail (between approximately 250,000 and 300,000 years) and water flux through the WPs starts.

The radionuclides that contribute most to the mean annual dose are shown on Figure 7.7.1-3[a]. $^{99}$Tc and $^{129}$I are the top dose contributors at the peak of the mean annual dose, which occurs around 12,500 years. Beyond about 30,000 years, $^{239}$Pu and $^{242}$Pu are the major dose contributors. In the sections that follow, the transport characteristics of $^{99}$Tc are discussed as an example of all highly soluble, weakly, or negligibly sorbing radionuclides. $^{239}$Pu and $^{242}$Pu provide examples of sparingly soluble, strongly sorbing radionuclides.

In order to investigate peaks in the mean annual dose curve, it was necessary to inspect two GoldSim realizations (representing two aleatory uncertainty vectors for the same epistemic uncertainty vector). One realization corresponds to an early CSNF WP failure, whereas the second corresponds to an early CDSP WP failure. Each affects expected annual dose at different times. Realization 5608 is chosen to represent the early failure of a CSNF WP, while realization 5618 is chosen to represent the early failure of a CDSP WP. These two realizations were chosen because both exhibit early failure of CSNF and CDSP WPs within percolation Subregion 3, which represents about 40 percent of the total repository area. Also, both represent a seeping environment, where releases are typically greater than from a non-seeping environment. The annual doses from these two realizations are highlighted on Figure 7.7.1-2[a], along with 18 other realizations representing aleatory uncertainty vectors for epistemic vector 281. These two realizations are examined more closely in the sections that follow.

### Early Failure CSNF Package—Realization 5608

Figure 7.7.1-4[a] shows the annual dose attributable to 21 radionuclides for realization 5608 (GoldSim filename: LA_v5.005_EW_006000_002.gsm; output DTN: MO0801TSPAMVAC.000 [DIRS 185080]). Two radionuclides, $^{99}$Tc and $^{129}$I, dominate the first sharp peak in dose at 12,000 years. There is a broad peak due to $^{239}$Pu between 20,000 and 100,000 years and a much broader peak after the DS fails at 292,000 years, due primarily to $^{242}$Pu and $^{237}$Np. At no time do radionuclides irreversibly attached to colloids contribute significantly to dose.

The peak dose (12,000 years) is due to the almost pulse-like releases of $^{99}$Tc and $^{129}$I from CSNF packages; these two radionuclides are transported essentially without retardation through the EBS, UZ, and SZ. In the Waste Package EF Modeling Case, the CSNF matrix is modeled to degrade instantaneously when the WP is breached and the temperature is above 100°C (Section 6.3.7.4.1.3 of the parent document). However, releases of radionuclides cannot occur until there is a continuous film of water within the WP to support diffusive transport, which is modeled to occur once the relative humidity rises above the threshold of 95 percent in the absence of flow. In realization 5608, the relative humidity exceeds 95 percent at 11,500 years, causing releases by diffusive transport to start. All of the highly soluble radionuclides (such as technetium and iodine) that are part of the CSNF inventory dissolve into the available water volume, establishing a large concentration gradient between the waste form domain and invert. This gradient drives diffusion and rapidly depletes the mass in the waste form domain. Figure 7.7.1-5[a] shows the technetium release rate from the waste form, invert (EBS), UZ, and SZ for realization 5608. The initial pulse-like release from the waste form is attenuated only slightly by transport through the WP corrosion products domain and the invert domain. As
indicated on Figure 7.7.1-5a[a], these two curves virtually coincide. The release rate is somewhat attenuated in the UZ and SZ due to hydrodynamic dispersion, which is caused by fracture-matrix interactions in the volcanic rock units and transport through alluvium. Figure 7.7.1-5b[a] shows the SZ breakthrough curves for technetium, reversibly attached plutonium, and irreversibly attached plutonium. The median SZ travel times for technetium for epistemic vector 281 range from 30 to 60 years over the four SZ regions. The small but sharp increase in the SZ release rate around 164,000 years (Figure 7.7.1-5a[a]) is due to a small step change in the SZ breakthrough curve from Source Region 2 reflecting coarse time discretization, rather than a physical process, which when convolved with the UZ release leads to such behavior.

In contrast to technetium, plutonium has a propensity to sorb strongly to most surfaces and also form a sparingly soluble solid, which results in entirely different geochemical behavior from that of the more soluble and weakly sorbing radionuclides like $^{99}$Tc. Unlike technetium, which exhibits a large pulse-like release, the release of plutonium from the waste form rises to a value below that of technetium and remains relatively constant for a long time (Figure 7.7.1-6[a]). This plutonium release characteristic reflects the fact that dissolved plutonium concentrations are solubility limited, whereas technetium concentrations are limited by the waste form degradation rates and transport rates. As a result, a considerable mass of plutonium released from the degraded waste form reprecipitates within the waste form domain. Figure 7.7.1-7a[a] shows dissolved plutonium concentrations within the CSNF waste form domain. All isotopes contribute to their dissolved elemental concentrations in proportion to their mass in the waste form cell; therefore, $^{239}$Pu dominates plutonium concentrations at early times and $^{242}$Pu dominates at later times (after most $^{239}$Pu has decayed). The mass of plutonium modeled as having precipitated in the waste form domain remains there as a solid ($\text{PuO}_2$) throughout the one-million-year simulation in realization 5608. The decrease in plutonium solubility observed around 292,000 years (Figure 7.7.1-7a[a]) is due to a change in the in-package chemistry from initiation of flow (about 0.14 m$^3$/yr) through the WP following the failure of the DS. This initiation of flow causes the in-package chemistry to be calculated based on the evaluation of both the vapor influx and liquid influx (Section 6.3.7.2.1 of the parent document), which results in the change in pH and ionic strength (Figure 7.7.1-7b[a]) and thereby the plutonium solubility. Note that CSNF colloids remain unstable throughout the simulation even though pH and ionic strength change (Figure 6.3.7-11b of the parent document), so the concentration of plutonium irreversibly associated with CSNF colloids remains minimal as seen on Figure 7.7.1-6b[a].

Besides solubility, sorption onto WP corrosion products controls the plutonium concentration and releases from the WP. The effect of sorption on the plutonium concentration within the WP corrosion products can be seen on Figure 7.7.1-6b[a], where there is an initial spike in the concentration which then decreases due to sorption. The spike results from the initial calculation of small $K_d$ on corrosion products as minimum initial values for the radionuclide concentrations are used by the surface-complexation based competitive sorption model to calculate the sorption coefficients. Once the radionuclide concentrations rise above the minimum values, the $K_d$s adjust to higher values in the next timestep (Figure 7.7.1-8[a]). The low initial $K_d$ allows a pulse of radionuclides, most notably $^{239}$Pu and $^{243}$Am, to be released through the WP corrosion products and sorbed onto the invert before significant $K_d$s are calculated in the corrosion products. This is a model limitation due to the explicit-in-time solution method for the competitive sorption calculations. However, the current implementation is adequate because it
causes only a minor over-prediction of the $^{239}\text{Pu}$ release to the invert in a single timestep. Because of decay of $^{243}\text{Am}$ to $^{239}\text{Pu}$, the dissolved concentration of $^{239}\text{Pu}$ in the WP corrosion products is calculated to exceed that in the waste form domain. In the subsequent timesteps, the establishment of higher $K_d$s causes the WP corrosion products domain $^{239}\text{Pu}$ concentration to drop below that of the waste form domain and then below that of the invert. As a result, there is backward diffusion from the invert into the WP corrosion products (represented by a negative release rate on Figure 7.7.1-6a[a]). Advective transport through the invert depletes the mass and eventually drops the concentration in the invert below that in the WP corrosion products and positive release from the WP to the invert is reinstated. The diffusion gradient between the invert and the UZ remains positive, however, resulting in continuous down-gradient releases (Figure 7.7.1-6a[a]). The release rates decrease in the UZ and further in the SZ, due to dispersion, sorption, and radioactive decay during transport. The SZ breakthrough curves for reversibly attached plutonium and irreversibly attached plutonium show median travel times of 16,000 to 39,000 years and 11,000 to 12,000 years, respectively (Figure 7.7.1-5b[a]). The small concentration of $^{239}\text{Pu}$ irreversibly attached to CSNF colloids in the waste form domain (Figure 7.7.1-6b[a]) shows that colloidal transport of $^{239}\text{Pu}$ is not important in this realization.

The release rate of $^{242}\text{Pu}$ (Figure 7.7.1-9a[a]) correlates well with its dissolved concentrations (Figure 7.7.1-9b[a]). The share of $^{242}\text{Pu}$ relative to the elemental solubility increases with time as mentioned earlier, so its concentration and release rate also increases. Release from the WP corrosion product domain is significantly reduced due to sorption onto the WP corrosion products. Unlike $^{239}\text{Pu}$ where the concentration in the WP corrosion products domain exceeded that in the waste form domain in the initial timestep due to ingrowth from decay of $^{243}\text{Am}$ (at 11,500 years), $^{242}\text{Pu}$ is not the daughter of a significant short-lived parent, and the concentration in the WP corrosion products domain remains below that of the waste form domain. At 292,000 years, the DS breaches so water flux through the WP starts and causes a sharp increase in the release rate from the WP.

### Early Failure Co-Disposed Package—Realization 5618

Figure 7.7.1-10[a] shows the contributions to annual dose by the major radionuclides for realization 5618 (GoldSim filename: LA_v5.005_EW_006000_003.gsm; output DTN: MO0801TSPAMVAC.000 [DIRS 185080]). Three radionuclides, $^{14}\text{C}$, $^{99}\text{Tc}$, and $^{129}\text{I}$, dominate the first peak, which starts around 1,000 years when the relative humidity of the CDSP WP rises above 95 percent. Although the CDSP WP is failed at the start of the simulation, only the DSNF is assumed to degrade instantaneously; whereas, the CDSP HLW glass degrades according to its temperature- and pH-dependent degradation rate (BSC 2004 [DIRS 169988], Section 8.1). Relative contributions from degradation of DSNF and HLW glass to combined waste form release for selected radionuclides is shown on Figure 7.7.1-11[a]. Radionuclides released from degraded DSNF are evident at the end of the first timestep (250-year duration), with a gradual rise in the cumulative release as the HLW glass degrades. The line for $^{14}\text{C}$ is flat because there is no $^{14}\text{C}$ inventory in the HLW glass. The slow degradation of HLW glass leads to a gradual release of $^{99}\text{Tc}$ from the HLW waste form domain (Figure 7.7.1-12[a]) compared to that from the CSNF waste form (Figure 7.7.1-5[a]). The lower inventory of $^{99}\text{Tc}$ within DSNF compared to that within CSNF (on a per-package basis; Table 6.3.7-5 of the parent document) results in a lower initial release rate. Once again a small but observable lowering and delay of the release rate peak occurs in the UZ and SZ (Figure 7.7.1-12[a]).
Figure 7.7.1-13a[a] shows the release rates of $^{239}\text{Pu}$ from the different domains. Figure 7.7.1-13b[a] shows the concentration of $^{239}\text{Pu}$ in each successive domain of the EBS transport model: HLW glass, DSNF, WP corrosion products, and invert. Each domain has a distinct chemistry and solubility control on plutonium concentration. Most plutonium is precipitated in both the HLW glass domain and the DSNF domain at the outset of the simulation but is depleted first in the DSNF domain by about 4,000 years. After that time, the concentration of plutonium in the DSNF domain is controlled by transport from the upstream HLW cell. Kinetic sorption and desorption processes, that are modeled in the WP corrosion products domain, control the concentration of plutonium and maintain it at the solubility limit. As diffusive release continues to the invert, the plutonium mass is depleted from the corrosion products domain and by 75,000 years, the dissolved concentrations cannot be maintained at the solubility limits leading to its gradual decline. This reduction in corrosion product domain concentration increases the concentration gradient between the HLW and WP corrosion products domains and increases the release rate from the waste form domain (Figure 7.7.1-13a[a]). Plutonium within the HLW glass waste-form domain is depleted after 176,000 years (Figure 7.7.1-14a[a]), and total plutonium release rate from the waste form domain drops to zero (Figure 7.7.1-13a[a]). In addition to the dissolved concentrations, Figure 7.7.1-13b[a] also shows the concentrations of $^{239}\text{Pu}$ irreversibly attached to glass waste form colloids. The ionic strength in the waste form domain (Figure 7.7.1-14b[a]) remains above the threshold for stable glass waste form colloid (Figure 6.3.7-11a of the parent document) until about 45,000 years, at which time stable colloids form. However, the concentration of $^{239}\text{Pu}$ irreversibly attached to waste form colloids remains orders of magnitude below the dissolved $^{239}\text{Pu}$ concentration. The net result is that the colloidal release of $^{239}\text{Pu}$ is not significant in realization 5618.

The release rate characteristics of $^{242}\text{Pu}$ from the various domains for the CDSP packages (Figure 7.7.1-15a[a]) are similar to those of $^{239}\text{Pu}$ (Figure 7.7.1-13a[a]), except that, due to its longer half-life (375,000 years), $^{242}\text{Pu}$ does not decay as quickly and later-time releases are significant. Just like $^{239}\text{Pu}$, $^{242}\text{Pu}$ becomes depleted in the DSNF domain at 4,000 years, but the concentration in the WP corrosion products domain remains steady due to sorption and desorption. Early in the simulation, the concentration of $^{242}\text{Pu}$ in the HLW waste form domain is low since the elemental concentration is dominated by the more abundant isotopes, $^{239}\text{Pu}$ and $^{240}\text{Pu}$ (Figure 7.7.1-14a[a]). As $^{239}\text{Pu}$ and $^{240}\text{Pu}$ decay, the concentration of $^{242}\text{Pu}$ increases, maintaining the dissolved concentration of total plutonium at the solubility limit (of about 0.0085 mg/L between 100,000 years and 280,000 years). At around 176,000 years the plutonium becomes depleted within the HLW waste form domain and the $^{239}\text{Pu}$ and $^{242}\text{Pu}$ concentrations drop (Figures 7.7.1-14a[a] and 7.7.1-15b[a]). As a result, the diffusion gradient from the WP corrosion products domain to the upstream waste form domain reverses, leading to increasing down-gradient release (represented by a positive release rate) and depletion of the mass in the waste form domain. Once the mass of plutonium has been depleted, the dissolved concentration of plutonium in the waste form domain decreases and plutonium once again diffuses from the WP corrosion products domain to the waste form domain (represented by a negative release rate on Figure 7.7.1-15b[a]). Initially, release of $^{242}\text{Pu}$ irreversibly attached to glass waste form colloids is low; however, after the DS fails, $^{242}\text{Pu}$ release increases due to advective release from the WP. This is the only significant release of colloidal radionuclides for this modeling case, with the release rate of irreversibly attached plutonium nearly equal to that of dissolved plutonium.
Waste Package Early Failure Modeling Case: Outlier

For the purpose of analyzing an outlier realization, epistemic vector 247 was chosen as shown on Figure 7.7.1-16[a]. Figure 7.7.1-17[a] shows the 20 aleatory realizations that are associated with epistemic vector 247 and correspond to GoldSim realizations 4921 through 4940. Two realizations (realization 4930 and 4940) are highlighted as they represent the highest unweighted dose for an early failed CSNF WP and a CDSP WP, respectively. The major radionuclide dose contributors for realizations 4930 and 4940 are shown on Figure 7.7.1-18[a]. The annual dose contributions from various aleatory vectors for the outlier epistemic vector 247 (Figure 7.7.1-17[a]) show the same general features as those shown for epistemic vector 281 discussed previously (Figure 7.7.1-2[a]): broad peaks between 1,000 and 10,000 years due to the contribution of $^{99}$Tc from early failed CDSP WP; a series of peaks between 10,000 and 30,000 years representing contribution of $^{99}$Tc from early failed CSNF packages located in various percolation subregions, where relative humidity increases above 95 percent threshold level at different times; and peaks due to $^{239}$Pu and $^{242}$Pu that occur after $^{99}$Tc peaks. Despite these similarities, the dose magnitudes are quite different among the two epistemic vectors: the magnitude of $^{99}$Tc dose is an order of magnitude higher for epistemic vector 247 and up to two orders of magnitude higher for $^{242}$Pu dose. Although all uncertain parameters are sampled separately among the two epistemic vectors, a comparison analysis reveals that these differences stem primarily from the sampled value of the probability of WP early failure with some contribution from differences in the solubility of plutonium in the WP and the SZ breakthrough curve for plutonium.

The probability of early failure of a WP (the $pW_i$ term of Equation 6.1.2-13 of the parent document, equivalent to GoldSim parameter UNC_WP_EF_conv_from_ln) is the weighting term used by EXDOC when computing the expected dose for an epistemic vector. This term is about an order of magnitude higher for epistemic vector 247 (sampled value of $4.6 \times 10^{-3}$ representing 99.98 percentile of the distribution) compared to that of epistemic vector 281 (sampled value of $3.3 \times 10^{-4}$ representing 94.77 percentile of the distribution) and is responsible mostly for the outlier behavior of epistemic vector 247. The unweighted annual doses from 20 GoldSim realizations for these two vectors are quite similar as shown on Figures 7.7.1-2[a] and 7.7.1-17[a], underlining the importance of the weighting factor in determining the expected dose.

Figure 7.7.1-19[a] shows the SZ breakthrough curves for epistemic vector 247. The median travel time for dissolved and reversibly sorbed plutonium (denoted as aqueous) ranges from 49,000 to 110,000 years, which is significantly longer than for epistemic vector 281 with median travel times of 16,000 to 39,000 (Figure 7.7.1-5b[a]). This explains the delay in the $^{239}$Pu peak in epistemic vector 247 compared to that in epistemic vector 281.

The mean plutonium solubilities within each EBS transport domain depends on the domain chemistry, but the sampled parameters Pu_Eps_1_low_a and Pu_Eps_1_high_a add uncertainty to the mean value thereby influencing the plutonium solubility throughout the EBS for both the CSNF and CDSP WPs. These parameters are above the 97th percentile for epistemic vector 247, but near the 50th percentile for epistemic vector 281, which causes an order of magnitude increase in the solubilities for epistemic vector 247. This is reflected in the higher concentrations within the waste form and WP seen on Figure 7.7.1-20a[a] compared to Figure 7.7.1-6b[a] and at early times on Figure 7.7.1-20b[a] versus 7.7.1-9b[a]. With the higher plutonium concentrations,
release is greater for epistemic vector 247. Unlike epistemic vector 281, \(^{242}\text{Pu}\) becomes depleted within the WP.

### 7.7.1.2[a] Drip Shield Early Failure Modeling Case

This section presents an analysis of two out of the 3,000 realizations selected from the realization base-case run performed for calculating the expected annual dose from the Drip Shield EF Modeling Case (GoldSim filename: LA_v5.005_ED_003000_000.gsm; output DTN: MO0710ADTSPAWO.000 [DIRS 183752]). The 3,000 realizations in GoldSim represent 300 epistemic uncertainty vectors where each epistemic vector is used for 10 aleatory uncertainty vectors.

In the stylized Drip Shield EF Modeling Case, a single CSNF or CDSP WP is modeled in a seeping environment under a DS that is assumed to be completely failed (breached) at the start of the simulation. Furthermore, the WP is assumed to fail completely from localized corrosion at the onset of drift seepage when the in-drift temperatures are still hot.

The expected annual dose from all 300 epistemic vectors, along with the statistics on the distribution of expected annual dose, is shown on Figure 7.7.1-21[a]. Figure 7.7.1-22[a] shows the major radionuclides that contribute to the mean annual dose. There is an early peak due to \(^{99}\text{Tc}\) and \(^{129}\text{I}\), whereas \(^{239}\text{Pu}\), \(^{242}\text{Pu}\), and \(^{237}\text{Np}\) are the top contributors later on. Epistemic vector 228 was chosen for further analysis because it has a shape similar to the mean annual dose curve and has a higher dose than the mean annual dose curve for the simulated duration (Figure 7.7.1-21[a]).

The expected annual dose from epistemic vector 228 is calculated as a weighted average of annual dose for ten aleatory vectors (Equation 6.1.2-14 of the parent document). The ten aleatory vectors that correspond to epistemic vector 228 are GoldSim realizations 2271 to 2280, and their unweighted annual dose histories are shown on Figure 7.7.1-23[a]. The ten aleatory vectors represent only the dripping environments in five percolation subregions for both CSNF and CDSP WP types. As outlined in Equation 6.1.2-14 of the parent document, the dose from each realization is then multiplied by the probability of early DS failure, the fraction of waste type, the seepage fraction, and the percolation bin fraction, the latter being equal to the number of WPs in the percolation subregion divided by the total number of WPs in the repository. These weighted doses are then summed to derive the expected annual dose for epistemic vector 228, shown on Figure 7.7.1-21[a]. GoldSim realizations 2273 and 2278 are highlighted on Figure 7.7.1-23[a] to show the relative difference in unweighted dose behavior between a CSNF WP type (realization 2273) and CDSP WP type (realization 2278) located in the same percolation subregion (percolation subregion 3). Both realizations are considered for further analysis in this section (GoldSim filenames: LA_v5.005_ED_003000_002.gsm and LA_v5.005_ED_003000_003.gsm; output DTN: MO0801TSPAMVAC.000 [DIRS 185080]). The major radionuclides contributing to dose for realization 2278 are shown on Figure 7.7.1-24[a], and they are similar to the major dose contributors for the mean annual dose (Figure 7.7.1-22[a]). The early part of the dose curve is dominated by \(^{99}\text{Tc}\), the middle part is dominated by \(^{239}\text{Pu}\), and the latest part is dominated by \(^{242}\text{Pu}\) (after \(^{239}\text{Pu}\) has decayed). \(^{79}\text{Se}\) is also important early on since no solubility-controlling solid for selenium is included in the TSPA-LA Model and it is retarded only moderately during transport (\(^{79}\text{Se}\) shows spiky behavior
later on due to the particle tracking algorithm used in the UZ transport model to track mass (Section 6.3.9 of the parent document)). The major radionuclides contributing to dose for realization 2273 are similar to the ones shown for realization 2278 and thus are not shown separately.

During the first 5,000 years, annual dose is dominated by the unretarded or weakly retarded species that have no solubility constraints, such as \(^{99}\text{Tc}, \text{^{79}Se}, \text{and} \text{^{14}C}\). After 5,000 years, and until about 250,000 years, \(^{239}\text{Pu}\) dominates dose (Figure 7.7.1-24a[a]). As shown on Figure 7.7.1-24b[a], the dose from \(^{239}\text{Pu}\) is a combination of dissolved plutonium and plutonium that is irreversibly sorbed onto colloids. The dose from \(^{239}\text{Pu}\) irreversibly associated with the slow traveling fraction of colloids is comparable to the dose from dissolved \(^{239}\text{Pu}\). At later times (after about 300,000 years), \(^{242}\text{Pu}\) is the dominant contributor to dose, as was demonstrated for the Waste Package EF Modeling Case discussed previously (Section 7.7.1.1[a]). Here again, the dose from \(^{242}\text{Pu}\) is a combination of dissolved and irreversibly sorbed colloidal plutonium (Figure 7.7.1-24b[a]). Unlike the Waste Package EF Modeling Case, releases from the WP in this Drip Shield EF Modeling Case are mainly advective with low ionic strengths, so that colloidal transport becomes important early on.

The transport behaviors described above and depicted on Figure 7.7.1-24[a] are expected because \(^{99}\text{Tc}, \text{^{79}Se}, \text{and} \text{^{14}C}\) are transported as solutes with little or no retardation in the engineered barrier and natural systems. Despite their similar transport properties and travel times to the biosphere, these three radionuclides exhibit variations in terms of dose due to differences in the initial inventory, decay rates, and biosphere dose conversion factors (BDCFs) for each of the radionuclides. In contrast to \(^{99}\text{Tc}, \text{^{79}Se}, \text{and} \text{^{14}C}\), the transport of \(^{239}\text{Pu}\) is strongly affected by retardation in the EBS, UZ, and SZ. This retardation is caused by reversible sorption onto WP corrosion products and inert material (crushed tuff) in the EBS and on the rock matrix in the UZ and SZ. Almost all the \(^{239}\text{Pu}\) that is associated irreversibly with colloids (embedded in HLW glass waste form colloids) is transported faster than dissolved \(^{239}\text{Pu}\) due to a lesser degree of fracture matrix interaction in the UZ and SZ, so that colloidal \(^{239}\text{Pu}\) contributes more significantly to dose earlier than dissolved \(^{239}\text{Pu}\).

**Releases from Engineered Barrier System**—The release of \(^{99}\text{Tc}\) out of the EBS occurs around 500 years for the CDSP WP and around 750 years for the CSNF WP, even though the WP fails early at the start of the simulation (Figure 7.7.1-25[a]). This delay is due to the effects of temperature since no transport (diffusive or advective) is allowed as long as temperatures remain above the boiling point of water (100°C). Figure 7.7.1-25[a] shows that the temperature within a CDSP WP does not fall below 100°C until approximately 400 years after closure and, for CSNF WPs, the temperature does not fall below 100°C until after approximately 600 years. [Note that the radionuclide transport related calculations start as soon as the WP temperatures drop below 100°C but the release rate information is not available as an output until the end of the user specified timestep. For the first 10,000 years of simulation in this modeling case, the selected timestep size is 250 years.]

A number of processes in both the WP and invert influence the release of radionuclides from the EBS. Figure 7.7.1-25[a] shows the mass flux of \(^{99}\text{Tc}\) out of the EBS into the UZ from both CSNF and CDSP WPs (from realizations 2273 and 2278, respectively). The \(^{99}\text{Tc}\) release curve for the CDSP WP starts around 500 years and initially decreases as drift-wall condensation flux
changes from Stage 2 to Stage 3 (discussed next). Technetium is released instantaneously from the CSNF WPs, dropping off rapidly on this log-log plot.

Figure 7.7.1-26[a] shows water flow rate into WPs as a function of time for CDSP and CSNF WPs. The initially high flow rate for the CDSP WP occurs during Stage 2 drift-wall condensation; that is, for those times between when the temperature at the first location in a drift drops below boiling and when the temperature at the last location drops below boiling (Section 6.3.3.2 of the parent document). Flow into the CDSP WP becomes equal to the seepage rate after 500 years, when Stage 2 ends. The CSNF package shows low initial seepage because there is no Stage 2 drift-wall condensation for the hotter CSNF WP.

Figure 7.7.1-26[a] also shows how seepage into each WP increases with each change in climate state because of corresponding increases in the percolation rate. Changes in climate occur around 600 years; 2,000 years; and 10,000 years; and each change in a climate state is marked by an instantaneous change in seepage rates through the EBS (Figure 7.7.1-26[a]). The small increase in seepage rates at about 2,000 years is in response to a change in climate state from monsoonal to glacial-transition. A considerably larger increase in seepage rate occurs around 10,000 years in response to the change in climate from glacial-transition to the post-10,000 year climate state with its higher percolation and higher seepage rate.

The fractions of each waste form that have degraded for CDSP and CSNF packages are shown on Figure 7.7.1-27[a]. The CSNF waste form is completely degraded when the WP fails at the start of the simulation because the temperature exceeds 100°C, and CSNF degradation is modeled as being instantaneous above this temperature. Although not shown on Figure 7.7.1-27[a], the same is true for DSNF, which is assumed to degrade instantaneously upon WP breach at all temperatures. On the other hand, HLW glass in the CDSP package (Figure 7.7.1-27[a]) degrades according to the modeled degradation rate, which declines gradually as WP temperature decreases until all of the HLW glass has degraded by about 10,000 years (in this realization).

Unsaturated Zone—After their releases from the EBS, radionuclides enter the UZ and are partitioned among the UZ fractures and matrix. Most radionuclide mass released from the EBS is partitioned into the UZ fractures because the DS is failed and the WP is in the seeping environment of the given percolation subregion, so that most of the transport is by advection. Figure 7.7.1-28[a] shows the fraction of mass released to the UZ fractures for selected radionuclides from a CDSP WP located in seeping environment of percolation subregion 3. The $^{239}$Pu mass in dissolved state and reversibly associated with colloids (denoted as aqueous) is differentiated from the mass irreversibly associated with slow traveling colloids, which is not in equilibrium with the mass in solution. Figure 7.7.1-28[a] shows that, at a minimum, 80 percent of the mass flux enters the UZ fractures but more commonly (at later times, especially beyond 10,000 years) greater than 95 percent of the mass flux is partitioned into the UZ fractures. The spikes down to zero (near the end of the simulation) are due to numerical approximations in the partitioning algorithm when essentially all of the $^{239}$Pu has decayed and the actual release is approximately zero. Because of fast transport times in the UZ fractures, there is little delay in the first arrival of radionuclide mass at the SZ, as shown on Figure 7.7.1-29[a]. Almost all of the $^{90}$Tc mass released from the EBS is also released out of the UZ in a short time and the cumulative release curves virtually overlay each other. However, only about 62 percent of the
$^{242}$Pu mass released from the EBS is released out of the UZ by 1,000,000 years. This reduction in the mass of $^{242}$Pu released from UZ is attributed to the diffusive interaction between UZ fracture and matrix continuum with sorption in the matrix that leads to reduced mass transport through the UZ, particularly for the repository release nodes located in the southern part of the UZ transport domain (SNL 2008 [DIRS 184748], Figure D.2-5[b]).

**Saturated Zone**—Transport of $^{99}$Tc through the SZ is relatively fast because it does not sorb to the SZ volcanic and alluvium units and almost all of the mass released out of the UZ is released from the SZ without any appreciable delay (Figure 7.7.1-29[a]). Transport of $^{242}$Pu in the SZ shows a small delay over the simulated time period despite the potential to be retarded considerably from sorption onto the volcanic and alluvium units. This is because, in this realization, one of the fastest SZ breakthrough curves is sampled (out of a set of 200 breakthrough curves) for transport of plutonium with a median travel time of less than 10,000 years (SNL 2008 [DIRS 183750], Figure 6-9[a]). Almost all of the $^{242}$Pu mass released out of the UZ is released from the SZ by the end of the simulated time period.

**Drip Shield Early Failure Modeling Case: Outlier**

For the purpose of analyzing an outlier realization, epistemic vector 244 was chosen as shown on Figure 7.7.1-30[a] because it has the highest annual dose from about 5,000 years to beyond 100,000 years for this Drip Shield EF Modeling Case. As discussed previously, each of the 300 curves shown on Figure 7.7.1-30[a] is a combination of ten aleatory vectors representing seeping environments in five percolation subregions for both CSNF and CDSP WP types. The unweighted annual dose from each of the ten aleatory vectors is multiplied by the corresponding probability of early DS failure, the WP type, the seepage fraction, and the percolation bin fraction, and then summed over aleatory vectors to derive the expected annual dose for the curve shown (Equation 6.1.2-14 of the parent document). Figure 7.7.1-31[a] shows the unweighted annual dose for the ten aleatory vectors corresponding to GoldSim realizations 2431 to 2440 for epistemic vector 244. Realization 2433 for the CSNF WP type is chosen for further analysis as it has a higher annual dose compared to a CDSP WP (e.g., realization 2438).

The major radionuclide dose contributors for realization 2433 are shown on Figure 7.7.1-32[a]. For the most part, the main contributors are similar to those in realizations 2273 and 2278 previously discussed. The major dose contributing radionuclide is $^{99}$Tc before 1,000 years as it is not solubility limited and transports unretarded through the EBS, UZ, and SZ. The dose from $^{99}$Tc decreases quickly as its inventory is depleted following waste form degradation. $^{237}$Np is the major contributor at 2,000 years and also beyond 200,000 years. The peak around 5,000 years is due to the slow traveling fraction of colloids with irreversibly sorbed $^{243}$Am and $^{239}$Pu. From 6,000 years to 200,000 years, a combination of dissolved and reversibly sorbed $^{239}$Pu mass on colloids (denoted as aqueous) and irreversibly sorbed $^{239}$Pu mass on colloids dominate the dose.

Although all uncertain parameters are sampled separately for each epistemic vector, a comparison analysis reveals that for epistemic vector 244, the high dose for radionuclides of interest stem primarily from the sampling of iron oxyhydroxide colloid concentration and the solubility uncertainties. The concentration of iron oxyhydroxide colloids from corrosion of stainless steel inside the WP is determined by the epistemic uncertain parameter,
Conc_Col_FeOx_SS_Sampled_a. This parameter has a sampled value of about 5.1 mg/L in realization 2433, which is at the 92nd percentile. For comparison, the value of this parameter in realization 2273 described earlier is about 0.076 mg/L, which is at the 45th percentile.

The solubility limits of both neptunium and plutonium are high in realization 2433. Equation 6.3.7-13a of the parent document shows the importance of $\varepsilon_1$ (the term accounting for thermodynamic uncertainty) in determining the solubility for neptunium and plutonium. Both neptunium and plutonium have high sampled values of $\varepsilon_1$ in realization 2433. As discussed in Section 6.3.7, neptunium solubility is controlled by NpO$_2$ when stainless steel is present in the WP and by Np$_2$O$_5$ after the stainless steel is gone. The sampled value of $\varepsilon_1$ for NpO$_2$ is at the 90th percentile and the sampled value of $\varepsilon_1$ for Np$_2$O$_5$ is at the 99.7th percentile. Np$_2$O$_5$ has a higher base solubility than NpO$_2$ so there is a jump in dose when the solubility controlling phase changes just after 200,000 years (Figure 7.7.1-32[a]). Plutonium also has an extremely high value of $\varepsilon_1$ as it is sampled at the 99th percentile in realization 2433. These high values of $\varepsilon_1$ for neptunium and plutonium mean high solubility limits in the WP.

Seepage fraction (that is used to determine fraction of WPs in a seeping environment) and seepage rate are both important parameters in the Drip Shield EF Modeling Case. Figure 7.7.1-33[a] presents the seepage fraction statistics of the Drip Shield EF Modeling Case run for 6,000 realizations along with the seepage fraction for realization 2433. The seepage fraction for realization 2433 is only slightly below the mean and median seepage fraction indicating that seepage fraction is not the reason for the high doses in this realization. Figure 7.7.1-34[a] presents the seep age rate statistics along with the seepage rate for realization 2433. The seepage rate for realization 2433 is above the mean past 2,000 years and at the 95th percentile beyond 10,000 years. This high seepage rate in this realization, when combined with a greater concentration of iron oxyhydroxide colloids and higher solubility limits for neptunium and plutonium, results in high advective release from EBS and a larger dose.

In addition to the higher release from the EBS, fast breakthrough curves in the SZ are sampled for neptunium and plutonium. Figure 7.7.1-35[a] shows the SZ breakthrough curves for neptunium and plutonium for the four SZ regions for realization 2433. These curves, particularly for Region 1, can be compared to the 200 possible breakthrough curves for Region 1 used in the SZ model that are shown in Saturated Zone Flow and Transport Model Abstraction (SNL 2008 [DIRS 183750], Figures 6-9[a] and 6-11[a]). The breakthrough curves for both neptunium and plutonium in realization 2433 appear to be in the fastest 5 to 10 percent of the 200 breakthrough curves. The short travel time in the SZ results in little decay in the natural system so the high EBS releases contribute to high dose.

7.7.1.3[a] Igneous Intrusion Modeling Case

This section presents analyses of two single realizations selected from among the 3,000 realization base-case runs used to calculate the expected annual dose from the Igneous Intrusion Modeling Case for a one-million-year simulation (GoldSim filename: LA_v5.005_IG_003000_000.gsm; output DTN: MO0710ADTSPAWO.000 [DIRS 183752]). The 3,000 realizations are the combination of 300 epistemic uncertainty vectors and ten aleatory uncertainty vectors that specify the times of igneous intrusion events. In other words, each realization of this modeling case has one igneous intrusion event occurring at a specified time.
with one given epistemic vector. The duration of the simulation for this modeling case is 1,000,000 years. The reader is referred to Sections 6.1.2 and 6.1.3 of the parent document for a discussion of how aleatory and epistemic uncertainties are treated and how expected annual dose is calculated for the Igneous Intrusion Modeling Case. Sections 6.5.1 of the parent document and 6.5.1[a] of this addendum provide details about the conceptual model, model abstraction, and TSPA-LA Model implementations for the Igneous Intrusion Modeling Case.

All WPs and DSs are assumed to have failed completely due to the igneous intrusion event so that the capabilities of both WP and DS to act as barriers to water flow are ignored. In addition, before the time of intrusion, only nominal corrosion is assumed for this modeling case, such that WPs could be breached by either SCC or by general corrosion and, thereby, subject radionuclides to potential release.

The mean annual dose and predominant radionuclides that contribute to it are shown for the base case on Figure 7.7.1-36[a]. This figure shows that the mean annual dose increases rapidly for the first 100,000 years to about 0.9 mrem, then decreases slightly to the value of 0.54 mrem at around 250,000 years, and then increases gradually for the remaining 750,000 years to a maximum of 0.89 mrem. The radionuclide that dominates dose early on (for the first 200,000 years) is $^{239}$Pu, with its contribution decreasing as it undergoes radioactive decay. While the contribution from $^{239}$Pu decreases, the contributions from $^{226}$Ra, $^{242}$Pu, and $^{237}$Np increase. At around 200,000 years, $^{242}$Pu overtakes $^{239}$Pu as the radionuclide that dominates dose. Beyond 250,000 years, $^{226}$Ra, $^{242}$Pu, and $^{237}$Np together account for more than two-thirds of the mean annual mean dose.

Expected annual dose from all 300 epistemic vectors is shown on Figure 7.7.1-37[a]. The expected annual dose of epistemic vector 286 is similar to the mean annual dose, which is why this epistemic vector was chosen for selecting the single realization used in the following analysis. Figure 7.7.1-38[a] presents the annual dose for the ten aleatory vectors that are associated with epistemic vector 286 and are represented by GoldSim realizations 2851 through 2860. Among these, GoldSim realization 2855, which has an igneous event occurring at 10,000 years, is chosen for the single realization analysis because its contribution to dose starts early. The model for GoldSim realization 2855 was run twice in order to first save information for all the percolation subregions and then to specifically save EBS cell-pathway details related to percolation subregion 3 under a seeping environment (GoldSim filenames: LA_v5.005_IG_003000_003.gsm and LA_v5.005_IG_003000_004.gsm; output DTN: MO0801TSPAMVAC.000 [DIRS 185080]).

This analysis of realization 2855 focuses on the four major contributors to dose mentioned above ($^{239}$Pu, $^{226}$Ra, $^{242}$Pu, and $^{237}$Np) plus $^{234}$U, whose transport behavior largely dominates the transport behavior of the decay product $^{226}$Ra. Note that the annual dose for realization 2855 decreases slowly (Figure 7.7.1-38[a]), which differs somewhat from the late-time trend of expected annual dose for epistemic vector 286 (Figure 7.7.1-37[a]). This difference is due to the fact that the expected annual dose includes contributions from additional aleatory vectors with later igneous events.

Figure 7.7.1-39[a] shows the time history of total annual dose (summed over all radionuclides) along with the contributions to annual dose from the five radionuclides selected for the analysis.
for realization 2855. A spike in total annual dose (~1,000 mrem) is noticeable immediately after the igneous intrusion event at 10,000 years. This spike is dominated by highly mobile radionuclides, primarily $^{99}$Tc, $^{129}$I, $^{14}$C, and $^{36}$Cl (none of which are shown on Figure 7.7.1-39[a]). Dose contributions from these four radionuclides decrease by about two orders of magnitude or more over the 10,000 years following the igneous event, so that by about 20,000 years after repository closure they contribute less than about 10 percent of the total annual dose (in this realization). For this reason, these four radionuclides are not analyzed in further detail in this section.

While dose contributions from these (and other) highly mobile radionuclides decrease, dose contributions from the four actinide radionuclides, $^{239}$Pu, $^{237}$Np, $^{234}$U, and $^{242}$Pu, increase until their contributions to total annual dose levels off between 28,000 and 130,000 years. After this, total annual dose decreases gradually for the duration of the simulation.

**Igneous Intrusion**—For GoldSim realization 2855, the igneous intrusion occurs at 10,000 years. The igneous intrusion fails all CSNF and CDSP WPs (total of 11,629 WPs) as well as the DSs. None of the WPs and DSs have failed by nominal corrosion processes prior to this event. Following the igneous intrusion, all WPs and waste forms experience high temperatures (peak expected temperature is 1,150°C) because of the heat of the magma. The high temperatures result in degrading all of CSNF instantaneously, oxidizing the UO$_2$ to U$_3$O$_8$, and making all non-uranium radionuclides available for release. Furthermore, because U$_3$O$_8$ has a high specific surface area (BSC 2004 [DIRS 169987], Section 6.2.2.2), the dissolution of U$_3$O$_8$ is also essentially instantaneous once contacted by water. The high temperature also results in rapid degradation of HLW glass. Five hundred years after the igneous event (i.e., a single timestep in the simulation during this time) WP temperature is calculated to have dropped to 52°C.

The various EBS environments affect waste form degradation and radionuclide mobilization differently for the Igneous Intrusion Modeling Case (discussed in Section 6.5.1.1.2 of the parent document) as compared to the Nominal Scenario Class (Section 6.3.4 of the parent document).

**EBS Releases**—The high degradation rates of CSNF and HLW allow the near-immediate release of their corresponding radionuclide inventories into solution. Because of solubility constraints, some radionuclides precipitate within the waste form domain of the EBS transport model. Following the igneous event, dissolved concentrations of neptunium, plutonium, and uranium from the CSNF waste form domain reach and are maintained at their solubility limits (Figure 7.7.1-40[a]). The solution (water) remains saturated with neptunium for about 40,000 years after the intrusion event while it is saturated with plutonium for about 200,000 years. The solution remains saturated with uranium throughout the simulation, owing to its large inventory. Dissolved radium concentrations, however, remain below the solubility limit in the CSNF waste form domain throughout the simulation. The dissolved concentration of radium increases early and is followed by a gradual decrease, due to the decay-chain ingrowth from $^{234}$U (half-life = 246,000 yr) and subsequent decay of $^{226}$Ra (half-life = 1,600 yr). The dissolved concentrations of neptunium and plutonium decrease rapidly once their precipitated solids have dissolved. As a result, their subsequent releases are not solubility controlled.

Gradual decreases in uranium, neptunium, and plutonium solubility limits (between 10,000 and 170,000 years) are caused by the gradual shift of pH towards neutral and a decrease of $P_{CO_2}$ over
that period (Figure 7.7.1-41[a]). The sharp increase in the solubility limit for neptunium at 172,000 years (Figure 7.7.1-40[a]) occurs because the solubility controlling phase is changed from NpO$_2$ to Np$_2$O$_5$ following complete degradation of all steel that can act as a reductant (i.e., an electron donor) inside the waste form domain (Section 6.3.7.5 of the parent document for further discussion).

As discussed in Section 6.5.1.1.1 of the parent document, every WP and DS is rendered incapable of protecting its contents after an igneous intrusion event. As a result, high seepage fluxes flow through each WP, and these fluxes are set equal to the local percolation flux after an igneous intrusion (Section 6.5.1 of the parent document) and range from 0.18 to 3.54 m$^3$/yr. This leads to rapid releases of radionuclides from the WPs once the temperature drops below the boiling point of water (Figure 7.7.1-42[a]). Note that two types of mass release rates for $^{239}$Pu and $^{242}$Pu are presented in Figure 7.7.1-42[a]: (a) the release rate of mass dissolved and reversibly sorbed on colloids (denoted as aqueous) and (b) the release rate that also includes the mass irreversibly associated with the colloids (denoted as total). Among the four radionuclides for this analysis, $^{237}$Np exhibits the highest release rate (approximately 550 g/yr), and its release rate decreases gradually as its inventory is depleted and its concentration declines. Releases of $^{242}$Pu, $^{234}$U, and $^{226}$Ra have trends similar to that of $^{237}$Np, whereas the release of $^{239}$Pu decreases rapidly because of its relatively short half-life ($2.41 \times 10^4$ years). Figure 7.7.1-42[a] also shows that most (greater than 90 percent) of $^{239}$Pu and $^{242}$Pu is transported as dissolved and reversibly sorbed on colloids, with the rest being transported irreversibly sorbed on colloids. For this reason, the irreversibly sorbed colloidal component of plutonium is not discussed in the rest of this analysis, and the release rates of $^{239}$Pu and $^{242}$Pu referred hereafter only include the mass dissolved and reversibly sorbed on colloids.

Figure 7.7.1-43[a] shows the advective and diffusive release rates of major radionuclides from CSNF WPs. It shows that advection is the major transport mechanism for radionuclides released from WPs for the Igneous Intrusion Modeling Case. Diffusion contributes less than one percent of the total release from WPs except for $^{242}$Pu at late time. Comparing Figure 7.7.1-43[a] with Figure 7.7.1-42[a] reveals that CSNF WPs are the dominant source for those major radionuclides.

Figure 7.7.1-44[a] presents the dissolved concentrations of neptunium, uranium, plutonium, and radium and their solubilities in the CSNF corrosion products domain for percolation subregion 3 under seeping environment. It shows that in the corrosion products domain, neptunium and plutonium concentrations maintain at their solubilities for a longer time than in the waste form domain (Figure 7.7.1-40[a]). However, unlike in the waste form domain, uranium concentration does not reach its solubility limit. Similar to the waste form domain, radium concentration does not reach its solubility limit. Moreover, dissolved concentrations of neptunium and plutonium decrease at slower rates than in the waste form domain because the corrosion products in the corrosion products domain gradually release neptunium and plutonium that had been sorbed onto corrosion product solids. The solubility controlled releases of $^{237}$Np and $^{239}$Pu are responsible for the ‘plateau’ in total dose between 28,000 and 130,000 years (Figure 7.7.1-39[a]).

Changes in radium solubility at 57,500 and 340,000 years are due to pH changes that cause the model to switch between two values of the radium solubility limit (Section 6.3.7.5.2 of the parent document). Changes in uranium solubility at those times also reflect changes in pH that cause
the model to switch between dissolved uranium concentrations being controlled by Na-boltwoodite solubility and schoepite solubility (Section 6.3.7.5.2 and Tables 6.3.7-56 and 6.3.7-57 of the parent document).

**Natural System**—Cumulative releases of $^{237}$Np, $^{242}$Pu, $^{234}$U, and $^{226}$Ra from the EBS, UZ, and SZ are presented in Figure 7.7.1-45[a]. Figure 7.7.1-45[a] shows a small delay for $^{237}$Np from the UZ and SZ of 500 years each (i.e., one timestep for each zone). This small delay is due to the fast transport predominately along the fracture pathways, with limited diffusion into the surrounding matrix. At the end of the simulation, 99 percent of neptunium that had been released from the EBS has migrated through the UZ, and 96 percent of that has migrated through the SZ. In other words, the UZ and SZ provide relatively minor retardation for $^{237}$Np in this realization of the Igneous Intrusion Modeling Case. This is attributed to the relatively small $K_d$ values assigned to neptunium. Similarly, $^{234}$U is not substantially retarded by the UZ and SZ on Figure 7.7.1-45b[a]. The figure shows that the cumulative release of $^{234}$U from the SZ after 330,000 years is higher than that from the EBS. This is not a numerical error but is caused by ‘inventory boosting’ performed at the UZ-SZ interface for transport through the SZ (Section 6.3.10.3 of the parent document).

Cumulative release of $^{242}$Pu shown on Figure 7.7.1-45c[a] illustrates the relative influences that the UZ and SZ have on delaying plutonium release. The UZ delays plutonium release for a few thousand years, whereas plutonium release is delayed for more than 10,000 years by the SZ. At the end of the simulation, about 24 percent of $^{242}$Pu that had been released from the EBS remains in the UZ, and 29 percent of $^{242}$Pu that had been released from the UZ remains in the SZ. The UZ and SZ both retard $^{242}$Pu significantly. This is attributed to the sorption of plutonium in the SZ volcanic matrix (as a result of fracture-matrix interactions) and alluvium.

The cumulative release history for $^{226}$Ra is presented on Figure 7.7.1-45d[a], which indicates that a large fraction of $^{226}$Ra released from the EBS does not exit the SZ. If radioactive decay and decay-chain ingrowth is ignored, then by 1,000,000 years, only 25 percent of $^{226}$Ra that had been released from the EBS would have migrated through the UZ, and less than 0.1 percent of $^{226}$Ra that had been released from the UZ would have migrated through the SZ. This substantial reduction in the mass of $^{226}$Ra is caused by the high $K_d$ values assigned to radium in the UZ and SZ (Tables 6.3.9-2 and 6.3.10-2 of the parent document) that serve to retard $^{226}$Ra transport through the UZ and SZ. When this delay is combined with the short half-life of $^{226}$Ra (1,600 years; Figure 6.3.7-4 of the parent document) it results in a significant decrease in the cumulative release from the SZ.

As pointed out previously, Figure 7.7.1-39[a] shows that the annual dose curve has a plateau that appears between 28,000 and 130,000 years. This plateau corresponds to the SZ groundwater concentration plateau of $^{237}$Np and $^{239}$Pu at the RMEI location for the same duration as shown on Figure 7.7.1-46[a]. The concentration plateaus correspond to the solubility controlled releases of neptunium and plutonium from the corrosion products domain shown on Figure 7.7.1-44[a]. Note that the SZ groundwater concentrations shown on Figure 7.7.1-46[a] are obtained by dividing the annual releases of radionuclides from the SZ by the 3,000 acre-ft/yr annual water usage, as per the regulatory requirements. Although the SZ groundwater concentration of $^{237}$Np is higher than that of $^{239}$Pu, the latter has a higher concentration dose conversion factor. As a result, $^{239}$Pu dose is higher than $^{237}$Np dose.
Figure 7.7.1-46[a] shows that for the first 500,000 years, the $^{234}$U concentration increases with time and then decreases; so does the $^{226}$Ra concentration. This suggests that $^{226}$Ra concentration is largely controlled by $^{234}$U concentration since the former is a decay product of the latter.

**Igneous Intrusion Modeling Case: Outlier**

For the purpose of analyzing an outlier realization for the Igneous Intrusion Modeling Case, epistemic vector 20 was chosen as shown on Figure 7.7.1-47[a] because it has the highest annual dose from about 50,000 years to about 300,000 years. Figure 7.7.1-48[a] shows the unweighted annual dose from 10 aleatory vectors, equivalent to GoldSim realizations 191 through 200, for epistemic vector 20. GoldSim realization 191 was chosen for further study, and the results are compared with GoldSim realization 2855 described earlier. In realization 191, the igneous event time is specified at 250 years and thereby occurs much earlier than for realization 2855, where it is specified at 10,000 years. Figure 7.7.1-49[a] shows the time history of annual dose and the contributions to annual dose from the selected radionuclides for realization 191. Four spikes in the total annual dose can be seen, with three prior to 10,000 years and the fourth being a broad peak past 10,000 years. The first spike (annual dose magnitude of about 1,100 mrem) occurs shortly after the igneous intrusion. This spike is caused by mobile radionuclides that travel unretarded through the engineered barrier and natural barrier system, such as $^{99}$Tc, $^{129}$I, and $^{14}$C.

The second spike (annual dose magnitude of about 400 mrem) occurs at 2,250 years shortly after a climate change from the monsoon to the glacial-transition climate. As shown in Figure 7.7.1-50[a], water flux through WPs increases due to the climate change, which causes higher advective releases and annual dose. The second spike is also caused by mobile radionuclides, such as $^{99}$Tc, $^{129}$I, and $^{14}$C.

The third spike (annual dose magnitude of about 900 mrem) occurs at 4,500 years. Dose contribution from $^{79}$Se dominates this spike. Selenium is moderately retarded in the UZ and SZ, as it has moderate $K_d$ values in the UZ and SZ (Tables 6.3.9-2 and 6.3.10-2 of the parent document). $^{79}$Se is not a major dose contributor in realization 2855 analyzed previously, nor in the base case (Figures 7.7.1-39[a] and 7.7.1-36[a]). Further analysis reveals that the sampled BDCF for $^{79}$Se in realization 191 is 123 times higher than that in realization 2855 (a sampled value of 2.73 (mrem/yr)/(pCi/l) versus $2.22 \times 10^{-2}$ (mrem/yr)/(pCi/l)). This is the primary reason for high $^{79}$Se dose in realization 191.

The fourth spike (annual dose magnitude of about 6,900 mrem) occurs around 50,000 years with $^{239}$Pu as the dominant radionuclide and the peak dose is about ten times higher than that in realization 2855 (Figure 7.7.1-39[a]). This is attributed to the higher solubility of plutonium in this realization, which is calculated to be about 0.105 mg/L in the CSNF waste form domain (Figure 7.7.1-51[a] compared to a value of about 0.005 mg/L for realization 2855 (Figure 7.7.1-40[a]). This difference (a factor of 21) is mainly caused by the difference in the sampled thermodynamic uncertainty values (the term $\varepsilon_1$ in Equation 6.3.7-13a of the parent document) for plutonium solubility (equivalent to GoldSim uncertain parameter Pu_Eps_1_low_a). In realization 191, the log of thermodynamic uncertainty is sampled to be 1.218 (at 96th percentile of the distribution), while for realization 2855, the sampled log value is -0.3428 (at 30th percentile of the distribution). The difference results in an increase in plutonium solubility by a factor of 36. Since there are other factors that modify the solubility, the actual
difference in plutonium solubility is smaller (21 times) than the difference in the sampled thermodynamic uncertainty.

The increase in $^{239}$Pu dose after 10,000 years is due to climate change at 10,000 years leading to increased flow rate through the WP (Figure 7.7.1-50[a]) and faster travel times through the UZ and SZ. Annual dose contribution from $^{239}$Pu decreases with time after 50,000 years, as the mass is depleted from the inventory and undergoes radioactive decay. Figure 7.7.1-51[a] shows that in the CSNF waste form domain, plutonium release is under solubility control until 156,000 years, while uranium release is under solubility control until 344,000 years. At later times, past 200,000 years, $^{242}$Pu, $^{237}$Np, $^{234}$U, and $^{226}$Ra overtake $^{239}$Pu as the major dose contributors and show behavior similar to that of realization 2855.

### 7.7.1.4[a] Seismic Ground Motion Modeling Case for One Million Years

This section presents an analysis of a single realization from the 9,000 realization base-case run performed for calculating the expected dose from the Seismic GM Modeling Case (GoldSim filename: LA_v5.005_SM_009000_003.gsm; output DTN: MO0710ADTSPAWO.000 [DIRS 183752]) for the one-million-year long simulation. The expected annual dose is presented on Figure 7.7.1-52[a], where each of the 300 realizations represents expected annual dose for one epistemic uncertainty vector. The expected annual dose for each epistemic uncertainty vector is generated by taking an expectation over a sample of 30 aleatory uncertainty vectors. More details about the computational methodology is provided in Sections 6.1.2.4.4 and 7.3.2.6.2 of the parent document. A single epistemic vector is selected for further analysis in such a manner that the expected annual dose is broadly representative of the modeling case and similar in behavior to the mean annual dose curve (Figure 7.7.1-52[a]). A separate outlier realization analysis is not included for 1,000,000 year Seismic GM Modeling Case because the epistemic vector chosen for the detailed analysis has an expected annual dose near or above the 95th percentile and could be considered an outlier realization.

Epistemic uncertainty vector 155 is selected for further analysis. The thirty corresponding aleatory vectors (sampling sequences) are represented by GoldSim realizations 4621 through 4650 (Figure 7.7.1-53[a]). Of these, the aleatory vector 21 (sampling sequence 21), which is equivalent to GoldSim realization 4641, is selected for detailed analysis (solid red curve on Figure 7.7.1-53[a]). The GoldSim file for realization 4641 was run twice: first to save information for all the percolation subregions and then to specifically save details of the EBS cell pathway related to percolation subregion 3 for the seeping environment (GoldSim filenames: LA_v5.005_SM_009000_004.gsm and LA_v5.005_SM_009000_005.gsm; output DTN: MO0801TSPAMVAC.000 [DIRS 185080]).

The annual dose from realization 4641 is presented on Figure 7.7.1-54[a], along with contributions to dose from individual radionuclides. The annual dose profile shows four major peaks, two of which occur before 100,000 years and the other two around 300,000 years and 500,000 years. Prior to 500,000 years, the radionuclides that dominate dose are $^{99}$Tc, $^{129}$I, $^{79}$Se, $^{239}$Pu, and $^{242}$Pu, after which dose is predominantly from $^{242}$Pu, with minor contributions from $^{135}$Cs and $^{237}$Np. The annual dose increases steadily after 700,000 years. There is no dose prior to 24,500 years.
Seismic events are modeled as a Poisson process and are generated randomly at the specified rate of $4.287 \times 10^{-4}$ yr$^{-1}$ (equal to the difference between maximum annual exceedance frequency of $4.287 \times 10^{-4}$ yr$^{-1}$ and the minimum annual exceedance frequency of $1 \times 10^{-8}$ yr$^{-1}$) (Section 6.6.1.3.2 of the parent document). Over the course of any simulation, several seismic events can occur with an average value of 429 total events (computed by multiplying the specified rate of the Poisson process, $4.287 \times 10^{-4}$ yr$^{-1}$, by the simulation time period of one million years). For realization 4641, a total of 460 seismic events occur over the simulated duration (Figure 7.7.1-55[a]). The horizontal component of the peak ground velocity (PGV) corresponding to each seismic event (also shown on Figure 7.7.1-55[a]) is calculated from the mean bounded seismic hazard curve (Section 6.6 of the parent document) by uniformly sampling the annual exceedance frequency between the minimum and maximum values for each event.

The probability of damage from an event is calculated separately for the CDSP and CSNF packages due to the inclusion of a transportation, aging, and disposal canister in the CSNF packages, which increases their structural strength. Though the response surfaces for the probability of damage are different for CDSP and CSNF packages, they are both functions of the PGV and the residual stress threshold (RST) of Alloy 22. The PGV value varies with each seismic event (as shown on Figure 7.7.1-55[a]), whereas the RST of Alloy 22 is treated as an epistemic uncertainty and held constant over the realization. The RST can vary uniformly from 90 percent to 105 percent of the yield strength, and the value of 91.92 percent for epistemic vector 155 indicates a sample from the lower end of the distribution. A lower RST value typically results in a greater probability of damage to the WP during a given seismic event; however, the actual damage depends on a number of other conditions, such as whether the WP has intact internals or degraded internals, whether the DS framework and plate are intact or not, and whether the WP is covered by rubble or not. Each of these conditions is determined separately.

Based on the DS plate and framework fragility analysis (Section 6.6.1.3.5 of the parent document), which is a function of DS plate and framework thicknesses at the time of the event; the fraction of the drift filled by rubble (in lithophysal zones) at event time; and the PGV of the event, the DS framework is not calculated to fail until 90,485 years and the DS plate does not fail until 267,465 years (Figure 7.7.1-56[a]). (The failure times are taken from calculations done in GoldSim filenames: LA_v5.005_SM_009000_004.gsm and LA_v5.005_SM_009000_005.gsm; output DTN: MO0801TSPAMVAC.000 [DIRS 185080].) At the time of DS plate failure, the fraction of drift filled by rubble is still less than half (about 0.43). Note that the failure time of the DS from rubble fill (due to seismic events) is computed to be much earlier than the expected DS failure time from general corrosion only, which is computed to occur around 307,000 years.

The time of initial damage to the WP due to a seismic event is determined separately for CDSP and CSNF WPs (Section 6.6.1.3.8 of the parent document) and is calculated as the earliest of the following three failure times:

1. The time of initial damage to the intact WP moving freely beneath the intact DS. The probability of damage is based on intact WP-internals abstraction by assuming a 23-mm thickness of the WP OCB and is a function of PGV and RST.
2. The time of initial damage to the WP surrounded by rubble after the DS (either framework or plate) is failed. The probability of damage is based on the damage abstraction for the degraded WP internals surrounded by rubble and is a function of PGV, RST, and WP OCB thickness.

3. The time of initial damage to the WP by puncture after the DS plate is failed. The probability of damage is a function of PGV and WP OCB thickness.

For a CDSP WP, initial damage is caused by the seismic event at about 24,100 years, which is calculated from the damage abstraction for the intact WP moving freely beneath the intact DS. (The failure times are taken from calculations done in GoldSim filenames: LA_v5.005_SM_009000_004.gsm and LA_v5.005_SM_009000_005.gsm; output DTN: MO0801TSPAMVAC.000 [DIRS 185080].) The DS failure times are much later than the CDSP WP failure times. The PGV of the seismic event is about 0.7 m/s, and the probability of damage is computed to be about 0.22 for the sampled RST of 91.92 percent, based on results presented on Figure 6.6-11a of the parent document. To determine if damage occurs, the probability of damage is compared to a random number generated by sampling a uniform distribution between 0 and 1 for each seismic event; if the probability of damage exceeds the random number, the WP is calculated to be damaged. At the event time of about 24,100 years, the random number is 0.15 and so the CDSP WP is considered to be damaged. All CDSP WPs fail at this time, as there is no spatial variability for seismic damage (ignoring the small variation in WP thicknesses across various percolation subregions). The number of CDSP WPs failing in each percolation subregion for both seeping and non-seeping environments is shown on Figure 7.7.1-57[a].

For CSNF WPs, the first damage from a seismic event is calculated to be past the simulation time period. This is possible since the probability of a CSNF WP getting damaged directly from a seismic event is extremely small (Figure 6.6-10a of the parent document). Therefore, in this realization, CSNF WP breaches from SCC caused by nominal processes occur much earlier than breaches due to seismic damage within the simulated time period (Figure 7.7.1-58[a]). The breach times calculated by WAPDEG differ for each percolation subregion due to variability in corrosion processes and thermal profiles for the WP. The time of the first breach of CSNF WPs in the various percolation subregions is as follows: 188,000 years in percolation subregion 1; 168,000 years in percolation subregion 2; and around 204,000 years in percolation subregions 3, 4, and 5. Failure of additional CSNF WPs from nominal processes occur based on the WAPDEG calculated WP failure history for each percolation subregion. The CSNF WP failure time history for each percolation subregion, for both seeping and non-seeping environments, is shown on Figure 7.7.1-58[a]. Noticeable jumps in the number of failed WPs around 300,000 years and 500,000 years reflect coarse time discretization used by WAPDEG at late simulation time periods.

In order to compute the representative WP damaged area for a given percolation subregion for performing radionuclide transport calculations, a conservative approach is adopted when the WP failures first occur due to nominal processes and fail over time. Following the first WP failure, the WP damage abstraction for degraded internals is used and any damage from subsequent seismic events is added to the previous damaged area for the representative WP. This time varying cumulative damage area computed for the first failed WP is then applied to other WPs in
the percolation subregion once they fail by either nominal processes or seismic ground motion, thereby maximizing the area for radionuclide transport. Since all CDSP WPs simultaneously fail around 24,100 years from seismic damage, the damaged area of a WP increases from zero to an initial small area due to the first appearance of cracks. It then increases from subsequent seismic events that cause damage but remains relatively small, as shown for percolation subregion 3 (Figure 7.7.1-59[a]). The initial damage area increases sharply past 49,000 years, followed by a few more increases from events that cause damage. After failure of the DS plate (around 268,000 years), the WP is assumed to be surrounded by rubble, and the probability of damage decreases considerably, leading to no additional damage from subsequent seismic events—until the seismic event that occurs at about 850,000 years. However, past 200,000 years there are small, gradual increases in the opening area due to continuing SCC from nominal processes. Beyond 500,000 years, patches from general corrosion processes start to appear and the total opening area increases rapidly. The breach area history for the CSNF WPs is similar to that for CDSP WPs, except for the start time which is much later, as shown for the percolation subregion 3 on Figure 7.7.1-60[a]. Following the first stress corrosion crack failure from nominal processes around 204,000 years, the opening area increases discretely (from further SCC) as a result of subsequent seismic damages, although there is some small gradual increase in the opening area due to continuing SCC from nominal processes. Nevertheless, the breach area remains relatively small until general corrosion patches appear after about 600,000 years.

Calculations of the seismically damaged area that use the degraded internals abstraction are based on the thickness of the WP OCB (Figures 6.6-10 to 6.6-17 of the parent document), in addition to the sampled PGV and the RST value. Two end-member seismic-damage abstractions are generally used in the TSPA-LA Model. One is based on the 23-mm OCB thickness applied if the OCB thickness is greater than or equal to 23 mm. The second abstraction is based on the 17-mm OCB thickness applied if the OCB thickness is less than or equal to 17 mm (this happens rarely and typically near the end of the simulated time period). For OCB thicknesses between 23 mm and 17 mm, the damage is based on the linear interpolation between the two end-member damage abstractions. Inside-out corrosion of the OCB begins once the WP is breached, which accelerates thinning of the WP OCB and makes it more susceptible to both seismic damage and general corrosion patches. Profiles of mean thicknesses of WP OCB for both CDSP and CSNF WPs in percolation subregion 3 are shown on Figure 7.7.1-61[a], along with WP failure fractions. The initial thicknesses of both types of WP are the same but diverge due to the initiation of inside-out corrosion of all CDSP WPs following seismic damage around 24,100 years. On the other hand, the CSNF WPs do not begin to fail until after 200,000 years, and they typically fail over an extended period. Thus, failed CSNF WPs are, on average, thicker than failed CDSP WPs, making CSNF WPs less susceptible to seismic damage and general corrosion induced patch failures compared to CDSP WPs. This is the primary reason for the smaller opening area and longer time taken for patches to appear on CSNF WPs (Figure 7.7.1-60[a]) compared to CDSP WPs (Figure 7.7.1-59[a]).

Because general corrosion patches on the WPs (either CSNF or CDSP) do not appear until 500,000 years or later, all mass released from failed WPs until that time is by diffusion through stress corrosion cracks (because no advective water flow is allowed through stress corrosion cracks). $^{99}$Tc is a major dose contributor, and its diffusive mass flux out of CDSP WPs for various percolation subregions is shown on Figure 7.7.1-62[a]. Note that the relative magnitude of release rates among percolation subregions is proportional to the number of failed WPs in
each percolation subregion (Figure 7.7.1-57[a]). Releases of \(^{99}\)Tc start when WPs are first damaged (around 24,100 years), then decrease over the next approximately 25,000 years as steady-state conditions are established. Release rates increase again around 49,500 years due to a sharp increase (about 30 fold) in the WP damage area (Figure 7.7.1-59[a]). Even though most of the HLW glass waste form has degraded by 40,000 years, including all of DSNF mass, not until about 55,000 years is most of the \(^{99}\)Tc mass released from the WP. This delay reflects the role of small cracks in reducing the rate of release, despite the lack of a solubility controlling solid for \(^{99}\)Tc and large concentration gradients across the WP.

In contrast, the diffusive mass flux of \(^{242}\)Pu (a major dose contributor past 500,000 years) out of the failed CDSP WPs remains relatively constant (Figure 7.7.1-62[b][a]). The release rate follows the WP OCB area opening curve, an indication that diffusive release of plutonium is proportional to the total WP opening area (Figure 7.7.1-59[a]). The slow relative release of \(^{242}\)Pu is maintained throughout the simulation for a variety of reasons, including (a) longer half-life of \(^{242}\)Pu (~375,000 years) compared to that of \(^{99}\)Tc (210,000 years), (b) the dissolved concentration inside the waste form domain is limited by the solubility controlling mineral phase (Section 6.3.7.5 of the parent document) so that not all of the degraded mass is available for release, (c) sorption of \(^{242}\)Pu in the corrosion products domain retards its transport and reduces the concentration gradient for diffusive flux, and (d) small diffusive areas associated with the WP OCB reduce the mass flux. Of these four factors, most important is sorption onto corrosion products. For example, in percolation subregion 3 for the seeping environment, 1,055 CDSP WPs fail around 24,100 years. Total initial \(^{242}\)Pu mass in the CDSP inventory (combined HLW and DSNF masses) is approximately 38.65 g/pkg (grams per CDSP package) (from Table 6.3.7-5 of the parent document, with an adjustment based on uncertainty in the inventory). By using the decay rate of \(1.85 \times 10^{-6}\) yr\(^{-1}\), the maximum mass of \(^{242}\)Pu at the time of WP breach would be about 36.97 g/pkg, and about 35.31 g/pkg at 49,000 years, when breach area increases (Figure 7.7.1-59[a]). Based on the results of the transport calculation, the mass of \(^{242}\)Pu sorbed onto corrosion products at 49,000 years is about 35.30 g/pkg, which accounts for just about all of the available mass. The mass is slowly released by desorption from corrosion products into the solution, thereby controlling both dissolved concentration (Figure 7.7.1-63[a]) and diffusive flux. Note that a mechanistic competitive sorption model that considers kinetic sorption and desorption is implemented for plutonium in the corrosion products domain (Section 6.3.8 of the parent document). As a result, variations in \(^{242}\)Pu concentration within the corrosion products domain are moderated, even though upstream concentrations (in the waste form domain) can vary over a larger range based on time-varying degradation rates and solubility limits.

The diffusive flux of \(^{99}\)Tc and \(^{242}\)Pu from all five percolation subregions for CSNF WPs is shown on Figure 7.7.1-64[a][a] and Figure 7.7.1-64[b][a]. The release from percolation subregion 2 precedes releases from other percolation subregions (as expected) because CSNF WPs fail in percolation subregion 2 first (Figure 7.7.1-58[a]). Figure 7.7.1-60[a] shows the evolution of the CSNF WP OCB opening area for percolation subregion 3 in a seeping environment. The \(^{99}\)Tc diffusive releases from CSNF WPs are sustained for a much longer time than are releases from CDSP WPs (compare Figure 7.7.1-64[a][a] to Figure 7.7.1-62[a][a]) due to the more gradual failure of CSNF WPs as shown on Figure 7.7.1-58[a]. However, once all CSNF WPs in a given percolation subregion have failed by nominal SCC (typically by about 550,000 years) and almost all of the CSNF waste form has degraded, the \(^{99}\)Tc mass is depleted relatively quickly out of the WP, but still takes over 10,000 years to be fully released (equivalent to fewer than three model...
timesteps at such late times). Compared to $^{99}$Tc release, diffusive release of $^{242}$Pu is more gradual and follows the breach area curve rather than the CSNF WP failure curve. The increase in diffusive releases after 800,000 years is caused by the patch opening that significantly increases the total WP breach area (Figure 7.7.1-60[a]) while the continued release of $^{242}$Pu from CSNF WPs is maintained by sorption-desorption reactions with corrosion products. Figure 7.7.1-65[a] shows the example for percolation subregion 3 for the seeping environment, where most of the $^{242}$Pu mass released from the inventory is sorbed on the corrosion products and then is gradually released by desorption, thereby controlling the dissolved concentration and diffusive release out of the WP (note that the curve showing the mass sorbed on corrosion products also includes the effects of radioactive decay).

The time histories for pH and ionic strength in the corrosion products domain for percolation subregion 3 for the seeping environment are shown on Figure 7.7.1-66[a]. The first sharp decline in ionic strength occurs around 380,000 years because that is the time when rubble completely fills the drift (a consequence of multiple seismic events, as shown on Figure 7.7.1-56[a]). At that time, the differential temperature and relative humidity time histories for high thermal conductivity rubble is imposed, leading to a small increase in relative humidity from 0.9956 to 0.9984. Since this increase in relative humidity corresponds to an equivalent increase in activity of water, it causes an appreciable decrease in ionic strength, indicating its high degree of sensitivity to relative humidity under vapor influx conditions (see Section 6.3.7.2.2 of the parent document for details on ionic strength abstraction). The second decline in ionic strength that occurs around 712,000 years is caused by water flowing through the WP after general corrosion patches have formed and exceeded a threshold of 0.1 L/yr, thereby leading to a change in the In-Package Chemistry Submodel (Section 6.3.7.2 of the parent document) from calculations based on vapor influx to calculations based on liquid influx. Despite the changes in ionic strength over the course of the simulation, pH in the corrosion products domain remains nearly constant as a result of buffering by surface complexation reactions.

Figure 7.7.1-67[a] compares (a) the concentration of $^{242}$Pu that is associated reversibly and irreversibly with colloids to (b) the dissolved concentration in the WP (corrosion products domain) for both CDSP and CSNF WPs for the seeping environment in percolation subregion 3. The concentration of dissolved and reversibly sorbed $^{242}$Pu mass on colloids (denoted as aqueous) overlays the dissolved concentration, indicating that the mass of $^{242}$Pu reversibly associated with colloids is negligible. The concentration of various colloid types over time for both CDSP and CSNF WPs are shown on Figure 7.7.1-68[a]. Different types of colloids become stable at different times based on their stability relationships as illustrated on Figure 6.3.7-11 of the parent document. CSNF waste form colloids remain unstable throughout the simulation and therefore maintain a constant minimum concentration. The HLW glass waste form colloids become stable first, followed by uranium colloids while there is no advection through the WP and ionic strength remains relatively high. Following the opening of general corrosion patches and advent of advective flow, groundwater colloids and iron oxyhydroxide colloids become stable primarily because of the appreciable decrease in ionic strength (for example, as shown in Figure 7.7.1-66[a] for CSNF WP).

Both reversible and irreversible sorption of plutonium is modeled on HLW glass waste form colloids while only irreversible sorption is modeled on the iron oxyhydroxide colloids and CSNF
waste form colloids. Only reversible sorption of plutonium is modeled on the groundwater colloids and uranium colloids. The sampled plutonium $K_d$ for HLW glass waste form colloids and groundwater colloids (both represented by smectite mineralogy) is about 1,700 mL/g, and the sampled plutonium $K_d$ for uranium colloids is about 247 mL/g. Due to the combination of small colloid concentrations and relatively small sampled $K_d$ for plutonium, the plutonium mass reversibly associated with colloids remains negligibly small compared to the mass in the dissolved state (Figure 7.7.1-67[a]). The concentration of $^{242}\text{Pu}$ irreversibly associated with HLW glass waste form colloids and iron oxyhydroxide colloids becomes significant at various times as shown on (Figure 7.7.1-67[a]).

Total EBS releases (i.e., summed over all percolation subregions) of $^{99}\text{Tc}$ and $^{242}\text{Pu}$ in the dissolved state, dissolved and reversibly associated with colloids (denoted as aqueous), and irreversibly sorbed on colloids for both CSNF and CDSP WPs are shown on Figure 7.7.1-69[a]. (The EBS release of $^{242}\text{Pu}$ mass irreversibly sorbed on CSNF waste form colloids is not shown as it is negligible due to the instability of those colloids.) The mass release of $^{99}\text{Tc}$ and $^{242}\text{Pu}$ (total) from CSNF WPs exceeds that released from CDSP WPs due to the greater number of CSNF WPs and larger inventory on a per package basis (Tables 6.3.7-1 and 6.3.7-5 of the parent document). It is interesting to note that, until the patches appear and advection starts, most of the $^{242}\text{Pu}$ mass released from the WP is in the dissolved state and very little is irreversibly associated with colloids (Figure 7.7.1-69[a]), even though the concentration of $^{242}\text{Pu}$ irreversibly associated with colloids is higher than the dissolved concentration in the WP (as shown by the example on Figure 7.7.1-67[a]). This is because prior to the opening of patches, since only diffusive release can occur through the WP, the colloid facilitated transport is limited by the diffusion coefficient of colloids, which is computed to be about 700 times smaller than that for the dissolved plutonium based on the sampled colloid particle diameter (SNL 2007 [DIRS 177407], Section 6.3.4.4). Once advection through the WP starts the transport of mass irreversibly associated with colloids becomes important.

The majority of the mass (combined for CSNF and CDSP WPs) that is passed from the EBS to the UZ at the repository horizon goes into fracture nodes in the UZ, rather than into the matrix nodes as shown on Figure 7.7.1-70[a] for $^{242}\text{Pu}$. This is because the majority of the WPs in a given percolation subregion (except for percolation subregion 1) are in the seeping environment where drift seepage that flows out through the invert carries the mass advectively through the fractures, even though most of the mass is diffusing out of the WP. For percolation subregion 1, the fraction of mass going into the fractures is initially relatively small (about 0.4) but increases (to approximately 0.9) around 81,500 years. This behavior is due to the change in seepage flux, which remains relatively small (about 0.005 m$^3$/yr) until around 81,500 years and then increases to about 0.08 m$^3$/yr. This is because at this time, the nonlithophysal locations are considered to be collapsed from drift degradation based on the drift seepage model abstraction, resulting in the seepage flux for such locations to change from the non-collapsed drift seepage to the percolation flux (Section 6.3.3.1.2 of the parent document). The effect of this change is greatest for percolation subregion 1 because, compared to other percolation subregions, it has (a) the smallest ambient seepage rates prior to the drift collapse and (b) the highest fraction of nonlithophysal locations (about 32 percent).

The cumulative mass releases from EBS, UZ, and SZ are compared on Figure 7.7.1-71[a] for $^{99}\text{Tc}$, $^{242}\text{Pu}$ (dissolved and reversibly sorbed on colloids; denoted as aqueous), and $^{242}\text{Pu}$
(irreversibly sorbed on all colloids). The transport characteristics are quite different for $^{99}\text{Tc}$ and $^{242}\text{Pu}$ in the UZ and SZ domains as $^{99}\text{Tc}$ is transported without retardation; whereas $^{242}\text{Pu}$ (aqueous) experiences considerable retardation due to sorption onto the tuff matrix and alluvium (Table 6.3.9.2 and Table 6.3.10.2 of the parent document). Little retardation is apparent in the UZ and SZ domains for $^{242}\text{Pu}$ irreversibly sorbed onto colloids because the diffusive interaction between fractures and matrix continua for mass irreversibly sorbed onto colloids is not modeled and, once the mass is placed in the fracture continuum, it tends to stay there. Although a small fraction (0.00168) of irreversible mass associated with colloids travels unretarded through the UZ and SZ (designated as the ‘fast fraction’; Section 6.3.8.3 of the parent document), almost all irreversible mass on colloids undergoes some retardation due to interaction between colloid particles and fracture surfaces. Despite this interaction, the mass irreversibly associated with colloids travels quickly through the UZ and SZ. As shown on Figure 7.7.1-71[a], almost all the mass released from the EBS, for both $^{99}\text{Tc}$ and $^{242}\text{Pu}$ (irreversibly sorbed onto colloids), is also released at the SZ model boundary within a relatively short period compared to the simulation time of 1,000,000 years. In contrast, the mass of $^{242}\text{Pu}$ (aqueous) released from the UZ and SZ model boundaries at the end of the simulation is appreciably smaller than that released from the EBS, indicating significant retardation (about 65 percent is released out of the UZ while only 31 percent is released out of the SZ). Since most of the mass is passed to the fracture nodes of the UZ, it diffuses from the fracture continuum into the matrix continuum due to fracture-matrix interaction in the UZ, with some mass also being transported into the matrix by advection due to lateral flow. Even though the free water diffusion coefficients in the UZ (as in EBS) vary by species (Table 6.3.9-3 of the parent document), the difference between $^{99}\text{Tc}$ and $^{242}\text{Pu}$ (aqueous) is relatively small (differ by a factor of 1.5) and can be ignored for most practical purposes. Thus, both $^{99}\text{Tc}$ and $^{242}\text{Pu}$ (aqueous) are equally likely to diffuse (assuming equal concentrations) from the fracture continuum into the matrix continuum. Because of sorption of $^{242}\text{Pu}$ in the UZ matrix, the concentration gradient between fracture and matrix is higher for $^{242}\text{Pu}$ than for $^{99}\text{Tc}$, leading to greater diffusive flux of $^{242}\text{Pu}$ into the matrix and smaller cumulative release at the UZ-SZ boundary.

In the SZ domain, the mass released from each of the four UZ regions is passed to the corresponding SZ region. In each SZ region, a location is randomly selected as the starting point for transport and is manifested through sampling one of the 200 pre-generated SZ breakthrough curves for a given species (Section 6.3.10.2 of the parent document). Due to their different transport characteristics through volcanic units and alluvium, separate sets of breakthrough curves are available for $^{99}\text{Tc}$, $^{242}\text{Pu}$ (dissolved and reversibly sorbed on colloids; denoted as aqueous), $^{242}\text{Pu}$ (fast traveling fraction irreversibly associated with colloids), and $^{242}\text{Pu}$ (slow traveling fraction irreversibly associated with colloids). The breakthrough curves are pre-generated as an impulse response function to a unit pulse and are convolved with the incoming UZ mass flux by using the convolution integral approach to produce the SZ mass flux at the location of the RMEI.

In this realization, SZ breakthrough curve number 122 was selected, and the breakthrough times of $^{99}\text{Tc}$, $^{242}\text{Pu}$ (dissolved and reversibly sorbed on colloids; denoted as aqueous), and $^{242}\text{Pu}$ (slow traveling fraction irreversibly associated with colloids) are compared for all four zones on Figure 7.7.1-72[a]. The breakthrough curves for $^{242}\text{Pu}$ (fast traveling fraction irreversible on colloids) are not presented as very little mass is transported by them. The breakthrough of $^{99}\text{Tc}$ from all four SZ regions is much earlier than that for $^{242}\text{Pu}$ (aqueous) and for $^{242}\text{Pu}$ (slow
traveling fraction irreversible on colloids), with almost half of the mass input recovered after a few hundred years of travel in the SZ for $^{99}$Tc compared to almost 100,000 years of travel time required for $^{242}$Pu (aqueous) and 10,000 years of travel time required for $^{242}$Pu (slow traveling fraction irreversible on colloids). However, the long tail noticeable in the breakthrough curve for $^{99}$Tc for the remaining half of its input mass results from longitudinal and transverse dispersion in the volcanic units and alluvium due to fracture-matrix diffusive interactions in the dual porosity volcanic domain of the SZ transport model. The $^{242}$Pu (aqueous) breakthrough is further impacted by sorption in both the volcanic matrix and alluvium. For SZ breakthrough curve 122, the initially sampled plutonium $K_d$ for volcanic matrix units is approximately 120 mL/g, and the initially sampled plutonium $K_d$ for the alluvium is 107 mL/g (SNL 2008 [DIRS 183750], Table A-1[b]). Both are modified in order to calculate effective $K_d$ values but nevertheless result in considerable retardation. Nearly all the plutonium (>0.999 fraction) is transported in the dissolved phase, with a small fraction (<0.001) being transported via reversible sorption on the groundwater colloids. This is because the groundwater colloid concentration sampled is about 0.11 mg/L and the $K_d$ for plutonium on the colloid is sampled to be about 6,560 mL/g, which when multiplied together, provides the fraction of the mass associated with colloids versus that transported in dissolved state. This fraction is equal to about 0.000722.

The release rates out of the SZ for $^{99}$Tc, $^{242}$Pu (dissolved and reversibly sorbed on colloids; denoted as aqueous), and $^{242}$Pu (irreversibly associated with colloids for both fast and slow traveling fractions) are shown on Figure 7.7.1-73[a] for realization 4641, and all three essentially follow their release rates out of the EBS when combined over CDSP and CSNF WPs (Figure 7.7.1-69[a]). The SZ releases are converted into annual dose by taking the annual releases out of the SZ for each radionuclide, dissolving them in the 3,000 acre-ft of water (annual usage at RMEI as defined by the regulation) to compute the mass concentrations, converting the mass concentration into concentration of radioactivity (in curies per liter of water), and then multiplying with the corresponding BDCFs computed for the modern-interglacial climate (present-day climate). The end result of this calculation is shown on Figure 7.7.1-54[a].

### 7.7.1.5[a] Nominal Modeling Case

This section presents an analysis of a single realization out of the 300 realization base-case run performed for calculating the expected annual dose from the Nominal Scenario Class (GoldSim filename: LA_v5.005_NC_000300_000.gsm; output DTN: MO0710ADTSPAWO.000 [DIRS 183752]). The Nominal Scenario Class consists of a single modeling case that represents a set of possible repository futures from which are excluded (1) disruptive events and (2) early failures of DSs and WPs. Moreover, the Nominal Modeling Case serves as a ‘reference system state’ from which all other modeling cases are developed (Section 8.2.1 of parent document). The distribution of expected annual dose for 300 epistemic vectors that also implicitly account for aleatory uncertainties (such as time, location, and degree of damage to each WP) is shown on Figures 7.7.1-74[a] (linear time) and 7.7.1-74b[a] (log time). Details about the calculation of the expected annual dose for this modeling case are described in Section 6.1.2.4.1 of the parent document.

The major radionuclides contributing to mean annual dose for this modeling case are shown on Figure 7.7.1-75[a]. Long-lived, highly-soluble, and mobile radionuclides, such as $^{90}$Tc and $^{129}$I, are the dominant dose contributors for most of the simulation, whereas long-lived,
sparingly-soluble, and strongly-sorbing radionuclides, such as $^{242}$Pu, $^{135}$Cs, and $^{237}$Np become important dose contributors at later times when contributions from $^{99}$Tc have declined.

Two minor peaks in the mean annual dose are apparent early on, at around 40,000 and 80,000 years (Figures 7.7.1-74[a]). These are the result of WPs failing by SCC from two realizations (out of the total of 300 realizations). After about 100,000 years, the mean annual dose steadily increases as a result of gradual WP failures. Step-wise increases in the mean annual dose noticeable around 200,000; 300,000; 500,000; and 700,000 years are due to increases in the number of WP failures (from SCC) calculated by the waste package degradation code WAPDEG V4.07 (STN:10000-4.07-01 [DIRS 181064]). WAPDEG calculates the corrosion rates at the timesteps provided in the WP thermal history input files from the multiscale thermohydrologic model (MSTHM) Abstraction (Section 6.3.2.3 of the parent document). The thermal history files have coarse temporal resolution past 100,000 years (due to small changes at late time periods) leading to evaluation of temperature at 200,000; 300,000; 500,000, 700,000; and 1,000,000 years. The stress corrosion crack growth rate is given by a power law function of stress intensity factor and repassivation slope $n$ (Equation 6.3.5-14 of the parent document). The stress intensity factor is evaluated at the beginning of each WAPDEG timestep and is a function of the crack depth that drives the crack propagation. The large timesteps taken past 100,000 years combined with the sensitivity of the crack growth rate to the stress intensity factor, which is raised to the power $4n$, where $n$ has a mean value of 1.165 (SNL 2007 [DIRS 181953], Table 8-15), can cause dramatic changes in the crack growth rate at each timestep. As a result, the crack growth rate can change from a small value for the timestep in which the crack initiates to a much larger value at the beginning of the next timestep, resulting in almost immediate penetration of many cracks and failure of WPs. An assessment of this temporal discretization for the Nominal Modeling Case is presented in Section 7.3.3.7[a].

**Nominal Modeling Case—Realization 286**

A single epistemic vector is selected for further analysis in such a manner that the expected annual dose is broadly representative of the modeling case and similar in behavior to the mean annual dose. Epistemic vector 286 is chosen for further analysis (Figure 7.7.1-76[a]), which is equivalent to GoldSim realization 286 (GoldSim filename: LA_v5.005_NC_000300_001.gsm; output DTN: MO0801TSPAMVAC.000 [DIRS 185080]).

Figure 7.7.1-77[a] shows the major radionuclides that contribute to the annual dose for realization 286 of the Nominal Modeling Case. Of these, $^{99}$Tc and $^{129}$I are the primary contributors with relatively minor contributions from $^{36}$Cl, $^{79}$Se, and $^{135}$Cs. Between 250,000 and 300,000 years, the annual dose for realization 286 exhibits local step increases that result from a single CDSP WP failure in the non-seeping environment of percolation subregion 2 and two CDSP WP failures in the seeping environment of percolation subregion 2. All three CDSP WP failures are caused by SCC failure on the outer lids prior to the DS failure, which occurs at 304,000 years.

The three significant step increases in the annual dose at 300,000; 500,000; and 700,000 years for realization 286 (Figure 7.7.1-77[a]) result from the coarse time discretization employed in WAPDEG V4.07 software leading to increased WP failures from SCC shortly following those times. A more detailed explanation of the effect of large timesteps on crack propagation is
Total System Performance Assessment Model/Analysis for the License Application

provided through an example calculation at the 500,000 and 700,000 year timesteps for percolation subregion 1, based on the sampled epistemic parameters for realization 286. The discussion will focus on incipient crack growth since they occur on every lid patch. Cracks due to weld flaws are ignored as they are much less frequent and are present on only a few WP lids in a given realization (Section 6.3.5.1.2 of the parent document). Incipient cracks initiate (nucleate) when general corrosion has penetrated to the depth at which the stress profile exceeds the threshold stress (critical depth). For realization 286 the threshold stress is sampled to be about 329 MPa (from a uniform distribution between 315.9 and 368.55 MPa; Table 6.3.5-3 of the parent document). Using the output table of stress versus depth generated by the SCCD V2.01 software (STN: 10343-2.01-01 [DIRS 181054]), evaluating at an angle of $\pi$ radians (one of the five choices of angles), the critical depth is found to be approximately 6.5 mm (see file WDStressO.fil located in the output DTN: MO0801TSPAMVAC.000 [DIRS 185080] in the path: LA_v5.005_NC_000300_001 (Nominal Single)\ Additional_Information\ Supplemental_Work_for_Analysis\ WAPDEG_out_files_from_PS1ND_only_run). To initiate the stress corrosion cracks by 500,000 years (equivalent to thinning the WP OCB by 6.5 mm), the general corrosion rate is calculated to be around 13 nm/year (ignoring the temperature effects). This value is within the uncertainty range of general corrosion rate (Figure 6.3.5-6 of the parent document), which typically ranges from 2 to 15 nm/year over a cumulative probability range of 0.1 to 0.9 for the medium uncertainty curve selected in realization 286. Using the output table of stress intensity factor versus depth generated by SCCD V2.01 software at an angle of $\pi$ radians, the stress intensity factor at 6.5 mm is found to be approximately 10.3 (MPa($\sqrt{m}$)) (see file WDKISCICO.fil located in the output DTN: MO0801TSPAMVAC.000 [DIRS 185080] in the path: LA_v5.005_NC_000300_001 (Nominal Single)\ Additional_Information\ Supplemental_Work_for_Analysis\ WAPDEG_out_files_from_PS1ND_only_run). The crack growth rate is then calculated from Equation 6.3.5-14 of the parent document to be 0.000005 mm/year (using the sampled value of 3.03×10^{-11} for $A$ and 1.29 for $n$). This rate when applied over the 200,000 year timestep (from 500,000 years to 700,000 years) would result in a crack growth of 1 mm. At 700,000 years (beginning of new timestep) the stress intensity factor is re-evaluated based on the new crack depth, which is the sum of the critical depth at 500,000 years (6.5 mm), the crack growth over 200,000 year period (1 mm), and the additional general corrosion thinning over 200,000 year period (2.6 mm using a general corrosion rate of 13 nm/year). The new stress intensity factor, evaluated at the current depth of 10.1 mm, would be approximately 39.4 (MPa($\sqrt{m}$)), which results in a crack growth rate of roughly 0.0054 mm/year and penetration of WP OCB (for remaining thickness of about 14.9 mm) in about 2,800 years after the start of the timestep. This calculation illustrates that the crack growth rates when recomputed over large time periods result in significant increase which in turn cause complete crack penetrations to occur shortly after the beginning of a new timestep leading to failure of large number of WPs.

Figures 7.7.1-78a[a] and 7.7.1-78b[a] illustrate the number and timing of WP failures within each percolation subregion for CDSP and CSNF WPs. These WP failures occur in both the non-seeping and seeping environments of each percolation subregion. Since there are about 2.4 times more CSNF WPs compared to CDSP WPs in the repository (8,213 CSNF WPs versus 3,416 CDSP WPs), relatively more CSNF WPs fail over the simulated duration. By the end of the simulation at 1,000,000 years, a total of 7,716 CSNF WPs have failed compared to a total of 3,227 failed CDSP WPs. The average WP failure area (breached area) time history for various
percolation subregions for CDSP and CSNF WPs are shown on Figures 7.7.1-79a[a] and 7.7.1-79b[a]. The breached area in all percolation subregions remains small throughout the simulation because WP failure is primarily from SCC. Only percolation subregion 1 for CSNF WPs has a (single) patch failure within the simulated time frame, which occurs past 950,000 years, leading to a small increase in area but even then the average breach area remains relatively small as the SCC failure area averaged over all failed WPs remains greater than the single patch failure area averaged over all the failed WPs. Thus, because only SCC failures occur on most WPs for the majority of the simulation, advective releases are negligible and radionuclides are primarily transported by diffusion out of the WP.

The rates at which $^{129}$I, $^{79}$Se, $^{135}$Cs, and $^{242}$Pu (dissolved and reversibly sorbed on colloids) are released over all percolation subregions from the EBS (as shown for waste form, WP, and invert), UZ, and SZ are shown on Figure 7.7.1-80[a] (for $^{129}$I), Figure 7.7.1-81[a] (for $^{79}$Se), Figure 7.7.1-82[a] (for $^{135}$Cs), and Figure 7.7.1-83[a] (for $^{242}$Pu). For $^{129}$I and $^{79}$Se, the curves that represent these release rates generally lie close to each other, which is indicative of each radionuclide being transported as a solute with little to no retardation through the engineered barrier and natural systems. The transport of $^{135}$Cs (as solute and reversibly sorbed on the colloids) exhibits the same behavior through the EBS and the UZ but has significant retardation through the SZ. For $^{242}$Pu (dissolved and reversibly sorbed on colloids), the mass released from the waste form is large relative to the mass released from the WP, invert, UZ, and SZ. This behavior reflects retardation due to sorption onto corrosion products inside the WP.

Figure 7.7.1-84[a] and Figure 7.7.1-85[a] compare the advective and diffusive releases of $^{129}$I and $^{242}$Pu (dissolved and reversibly sorbed on colloids) from all failed WPs in all percolation subregions. There is no advective release from CDSP WPs as there is no general corrosion patch failure. However, because there is corrosion patch failure for CSNF WPs in percolation subregion 1 past 950,000 years, there is some advective release, but it is still negligible compared to diffusive release. The advective release for $^{242}$Pu (dissolved and reversibly sorbed on colloids) is not shown as it is below the cut-off scale for the plot. The step increase in diffusive releases coincides with the step increases in WP failures, but beside the step changes, the diffusive release remains steady for $^{129}$I and shows gradual increase for $^{242}$Pu that is dissolved and reversibly sorbed on colloids. This is attributed to the relatively steady rate of WP failures between the step changes (Figure 7.7.1-78[a]). Thus, although more WPs are failing with time, the rate of WP failure remains relatively steady, thereby maintaining steady releases of $^{129}$I even after accounting for large diffusive flux due to high concentration gradient. The release of $^{242}$Pu, in contrast, in addition to being similarly affected by the rate of WP failure, is also impacted by relatively low aqueous solubility and sorption on the corrosion products inside the WP, which reduce the concentration gradient. Combined with a small breach area per package (Figure 7.7.1-79[a]), these factors cause $^{242}$Pu to be released slowly from each failed WP. As a result, as more WPs fail through time, the $^{242}$Pu release rate increases gradually. Releases from CSNF WPs dominate that of CDSP WPs because (a) comparatively more CSNF WPs are failed and (b) there is comparatively larger inventory for the radionuclides of interest on a per package basis in a CSNF WP. Note that results for $^{99}$Tc, $^{36}$Cl, and $^{79}$Se are not shown separately as they demonstrate similar transport characteristics as $^{129}$I.

As previously shown on Figures 7.7.1-80[a] through 7.7.1-83[a], the release rates of $^{129}$I are quite different from those for $^{242}$Pu but are generally similar to $^{99}$Tc, $^{36}$Cl, and $^{79}$Se. $^{129}$I is transported
as an unretarded species through the EBS, UZ and SZ, and nearly all of the mass released from
the waste form travels quickly through the EBS (WP and invert), UZ, and SZ. The mass fraction
of $^{129}$I passed to the UZ matrix and fracture continuum from the EBS at the repository level is
shown on Figure 7.7.1-86[a]. The fraction of mass released to UZ fracture increases from
percolation subregion 1 to 5, in proportion to the seepage fraction assigned to various percolation
subregions (Section 6.3.3.1.3 of the parent document). The seepage fraction determines the
fraction of WPs assigned to the seeping environment versus the non-seeping environment within
a percolation subregion. Since $^{129}$I is neither sorbed nor limited by solubility, the diffusive mass
release from the WP remains largely a function of waste form degradation rate and concentration
inside the WP. The change in the WP to invert concentration gradient between non-seeping
environment and seeping environment due to flow through the invert has limited effect on the
diffusive releases of $^{129}$I per failed WP. Thus the fraction of $^{129}$I mass passed to UZ fracture for a
given percolation subregion is proportional to the number of failed WPs in a seeping
environment compared to the non-seeping environment and thus directly related to the seepage
fraction, which increases from percolation subregion 1 to 5. [Note: Although no water is
modeled to flow advectively through the WPs due to the presence of stress corrosion cracks, the
in-drift seepage in the seeping environments flows around the WPs (and DSs) to the invert and,
thus, the diffusive releases out of the WP are carried primarily by advection from the invert into
UZ fracture continuum with less mass release into the matrix continuum. In the non-seeping
environment the transport through the invert is primarily by diffusion into the matrix continuum
due to large effective diffusive area of the matrix continuum (Section 6.3.8.3 of the parent
document).]

The mass fraction of $^{242}$Pu (dissolved and reversibly sorbed on colloids) passed to the UZ matrix
and fracture continuum from the EBS at the repository level is shown on Figure 7.7.1-87[a]. In
contrast to the mass fraction of $^{129}$I, a relatively larger fraction of $^{242}$Pu is passed into the
fractures, indicating a disproportionately larger contribution from WPs located in the seeping
environments compared to the non-seeping environment. This is because highly sorbed species
such as $^{242}$Pu have a lower concentration in the WP than a nonsorbing species such as $^{129}$I, and
the diffusive flux is primarily controlled by concentration gradient between the WP and the
invert. In the seeping environment the flow through the invert causes the concentration gradient
to increase (due to reduction in distance to the effective zero concentration boundary from the
WP) leading to disproportionately larger diffusive mass flux from the seeping environment per failed WP. As a result, most of the $^{242}$Pu mass released in a
given percolation subregion is from the contribution of WPs in the seeping environment that are
released to the UZ fracture continuum.

Transport through the SZ for each radionuclide is governed by sampling a breakthrough curve
from 200 pre-generated breakthrough curves applicable to each radionuclide. The breakthrough
curves are abstractions of more complex SZ flow and transport modeling studies. Each
epistemic realization randomly samples a number from 1 to 200, and that sampled number
represents the set of species-specific breakthrough curves to be used in that particular realization.
For realization 286, breakthrough curve set 33 is selected. Solute transport of $^{129}$I and $^{79}$Se in the
SZ is relatively quick due to no retardation modeled for $^{129}$I and limited retardation for $^{79}$Se
(sampled $K_d$ of about 8.3 mL/g and 6.7 mL/g in the SZ volcanic matrix and alluvium,
respectively) as shown by release rates for SZ when compared to UZ in Figures 7.7.1-80[a] and 7.7.1-81[a]. In contrast, dissolved $^{242}$Pu (with sampled $K_d$ of about 84 mL/g for SZ volcanic
matrix and 87 mL/g for SZ alluvium) and, to a much greater extent, dissolved $^{135}$Cs (with sampled $K_d$ of about 5986 mL/g for SZ volcanic matrix and 563 mL/g for SZ alluvium) undergo sorption while being transported through the SZ and hence are retarded (Figures 7.7.1-83[a] and 7.7.1-82[a]).

$^{242}$Pu is one of the radionuclide species that is transported both dissolved and reversibly sorbed on colloids and irreversibly associated with fast traveling and slow traveling fraction of colloids. Figure 7.7.1-88[a] shows the contribution to the mean annual dose of $^{242}$Pu (dissolved and reversibly sorbed on colloids; denoted as aqueous) and associated irreversibly with colloids (for both traveling fast and slow). While colloidal $^{242}$Pu exists as a species in the natural system, its contribution to the mean annual dose is very small and the majority of the dose is from the dissolved $^{242}$Pu.

**Nominal Modeling Case: Outlier**

For the purpose of analyzing an outlier realization for the Nominal Modeling Case, epistemic vector 85 (equivalent to GoldSim realization 85) was chosen as shown on Figure 7.7.1-89[a] because it has the highest annual dose at 1,000,000 years. As shown on Figure 7.7.1-90[a], $^{242}$Pu is the major radionuclide contributor to the dose past 700,000 years. The release rates for $^{242}$Pu from the waste form, WP, invert, UZ, and SZ are shown on Figure 7.7.1-91[a]. For realization 85, the release of $^{242}$Pu from the waste form starts earlier and occurs within a shorter time frame leading to an order of magnitude higher release rates compared to the gradual release for realization 286 (Figure 7.7.1-83[a]) that occurs over extended time periods. This difference in waste form release rate stems primarily from the difference in WP failure rates due to SCC on the outer lids of the WP from nominal processes. As shown on Figure 7.7.1-91b[a] for realization 85, the CSNF WP failure in all percolation subregions starts past 160,000 years and by about 500,000 years, all WPs are failed. In comparison, for realization 286, the CSNF WP failures (Figure 7.7.1-78b[a]) occur over a longer time frame starting around 300,000 years and continuing until the end of simulation at 1,000,000 years.

For realization 85, the peak release of $^{242}$Pu from waste form occurs around 300,000 years. But due to sorption of plutonium on the corrosion products inside the WP, significant retardation of $^{242}$Pu occurs inside the WP, and the peak release out of the WP is delayed until around 900,000 years indicating long residence times inside the WP on the order of 500,000 to 600,000 years. Because the WP release rates control the release behavior out of the UZ and SZ (Figure 7.7.1-91a[a]), it indicates that sorption and resulting retardation is the primary control on annual dose. The release rate of $^{242}$Pu for realization 286 shows similar behavior (Figure 7.7.1-83[a]) as the sorption inside the WP reduces the release rate. However, because the peak waste form release does not occur until around 800,000 years, the peak release from the WP is not seen within the simulated time period as it is anticipated that the peak releases from the WP would be delayed by 500,000 to 600,000 years.

Thus, due to a combination of earlier WP failure start times and faster failure rate, the mass released from the waste form is also mostly released from the WP within the simulated time period. This results in a higher annual dose magnitude for realization 85.
7.7.1.6[a] Human Intrusion Modeling Case

This section presents an analysis of a single realization from the 9,000 realization base-case run performed for calculating the expected dose for the Human Intrusion Modeling Case for the 1,000,000-year simulation duration (Base Case GoldSim Run filename: LA_v5.005_HI_009000_000.gsm; output DTN: MO0710ADTSPAWO.000 [DIRS 183752]).

The expected annual dose is presented in Figure 7.7.1-92[a], where each of the 300 realizations represents expected annual dose for one epistemic uncertainty vector. The expected annual dose for each epistemic uncertainty vector is generated by taking an expectation over a sample of 30 aleatory uncertainty vectors (for more details on the computational methodology, refer to Section 6.1.2.5 of the parent document). A single epistemic vector is selected for further analysis such that its expected annual dose is broadly representative of the modeling case and similar in behavior to the mean annual dose curve (Figure 7.7.1-92[a]).

The epistemic uncertainty vector 277 is selected for further analysis. The 30 corresponding aleatory sampling vectors for the selected epistemic vector correspond to GoldSim realizations 8281 through 8310 (Figure 7.7.1-93[a]). The annual dose from the 30 aleatory vectors falls into two groups: (1) the group with higher dose represents those realizations in which a CSNF WP is selected, and (2) the group with lower dose represents those realizations in which a CDSP WP is selected. The specific realization selected for further analysis is GoldSim realization 8309 (Figure 7.7.1-93[a]), which is chosen from the first group (representing releases from a CSNF WP). Realization 8309 represents aleatory uncertainty vector 29, in which the CSNF WP breached from a human intrusion event is located in percolation subregion 4 of the EBS and where the mass from the UZ borehole is passed to SZ source region 1 (GoldSim filename: LA_v5.005_HI_009000_002.gsm; output DTN: MO0801TSPAMVAC.000 [DIRS 185080]).

In the stylized Human Intrusion Modeling Case, a borehole pathway is modeled as being drilled directly through a single DS and WP vertically down to the water table. The time of this intrusion, which is assumed to result from exploratory drilling for ground water, is fixed at 200,000 years. Once the WP is breached, the waste form degrades by nominal degradation processes and the radionuclides are transported from the WP under nominal conditions to the vertical UZ borehole pathway, such that the mass is released at the water table for transport through the SZ to the RMEI at the regulatory boundary. The vertical borehole pathway is modeled as being 190 meters in length and conceptualized as a dual-porosity medium consisting of a discrete vertical fracture surrounded by matrix consisting of rubble from partial collapse of the borehole. The fracture is assumed to be open so that the water that flows in the borehole moves through the fracture pathway. Also, the radionuclide mass released from the WP (by diffusion and advection) is passed to the fracture pathway where it undergoes vertical advection within the fracture and lateral diffusion into the surrounding matrix due to fracture-matrix interaction. No retardation of colloids or solute is modeled on the fracture surface although species-dependent sorption coefficients are applied in the matrix (for additional details, refer to Section 6.7 of the parent document).

The major radionuclides contributing to annual dose for realization 8309 are shown on Figure 7.7.1-94[a], along with the total annual dose. $^{99}$Tc and $^{129}$I are the early major dose contributors (before 300,000 years), following the WP breach at 200,000 years, whereas $^{242}$Pu becomes the dominant dose contributing radionuclide later on (with minor contribution from
The early contribution to dose from \(^{99}\)Tc and \(^{129}\)I occurs because they travel unretarded through the WP, UZ borehole pathway, and SZ. By contrast, \(^{242}\)Pu, \(^{237}\)Np, \(^{135}\)Cs, and \(^{233}\)U are retarded in these transport pathways to varying degrees and therefore contribute to dose much later. Because \(^{99}\)Tc and \(^{242}\)Pu are the dominant radionuclides with very different transport properties, they have been chosen for further analysis.

The cumulative mass release of \(^{99}\)Tc and \(^{242}\)Pu from the waste form inventory following the failure of one CSNF WP is shown on Figure 7.7.1-95[a]. The waste form starts degrading following the breach at 200,000 years, and due to the relatively slow CSNF degradation rate (about \(6.9 \times 10^{-5}\) yr\(^{-1}\)), it is almost fully (0.99 fraction) degraded by 268,000 years. The rate at which \(^{99}\)Tc is released from the waste form domain and the corrosion products domain of the WPs is shown on Figure 7.7.1-96[a]. Because the dissolved concentration of \(^{99}\)Tc is not limited by a solubility controlling solid, the mass of \(^{99}\)Tc released from the degrading waste form is quickly transported out of the WPs by advection and diffusion. In this realization, the volumetric water flux through the WP (and going to the UZ borehole) is calculated to be about \(8.7 \times 10^{-4}\) m\(^3\)/yr (which is equivalent to the calculated percolation rate of about 26.9 mm/yr for the drilled borehole cross-sectional area of 0.0324 m\(^2\) [Table 6.7-5 of the parent document]). Diffusive releases are higher than advective releases through the WP (in both waste form and corrosion products domains) because of the implementation of a zero concentration boundary just outside the WPs to maximize the concentration gradient. Almost all of the \(^{99}\)Tc mass is released by about 300,000 years, as indicated by the negligibly small release rates past this time period (Figure 7.7.1-96[a]). The waste form degradation primarily controls the release of \(^{99}\)Tc out of the WPs. After the \(^{99}\)Tc mass is made available for transport, it is released out of the WPs without appreciable delay.

The \(^{242}\)Pu mass release from the waste form domain and the corrosion products domain of the WP are shown on Figure 7.7.1-97[a]. \(^{242}\)Pu is modeled as being transported both as dissolved and reversibly sorbed on colloids (denoted as aqueous) and as irreversibly sorbed onto iron oxyhydroxide colloids and waste form colloids. Note that CSNF waste form colloids remain unstable throughout the simulation (and are set to a minimum defined concentration) so they contribute negligibly to the total mass released, whereas iron oxyhydroxide colloids remain unstable for a short period, until about 220,000 years, and contribute to the mass release afterwards. The diffusive release of \(^{242}\)Pu (dissolved and reversibly sorbed on colloids) exceeds advective releases as most of the \(^{242}\)Pu mass remains in dissolved state, with very little being reversibly sorbed onto groundwater and uranium mineral colloids. However, the mass that is irreversibly sorbed on the iron oxyhydroxide colloids is predominantly transported by advection (Figure 7.7.1-97[a]) due to the small diffusion coefficient of colloids. The concentration of \(^{242}\)Pu that is dissolved, and that which is irreversibly sorbed onto iron oxyhydroxide colloids, are both shown on Figure 7.7.1-98[a] for the waste form domain and the corrosion products domain. The dissolved concentration in the waste form domain is limited by the solubility of plutonium dioxide (PuO\(_2\)) in the waste form domain for several hundred thousand years following the breach. Because the solubility of PuO\(_2\) is low, most \(^{242}\)Pu mass from the degraded waste form is precipitated early in the waste form domain. Plutonium is gradually depleted from the waste form domain by diffusion and advection, and not until 748,000 years is enough mass depleted to cause the plutonium concentration inside the waste form domain to drop below the solubility limit. The dissolved concentration of \(^{242}\)Pu in the corrosion products domain remains small initially, as \(^{242}\)Pu is sorbed onto corrosion products whose mass increases over time from
degradation of steel. By 320,000 years, all of the steel in the corrosion products domain is degraded, and the maximum sorption capacity for the corrosion products domain is reached. As $^{242}$Pu continues to be transported from the waste form domain to the corrosion products domain, the dissolved concentration of $^{242}$Pu in the corrosion products domain starts to build up after 320,000 years, reaching the solubility limit in that domain, which is maintained until all $^{242}$Pu mass has been depleted in the waste form domain and the concentration of $^{242}$Pu drops at 748,000 years (Figure 7.7.1-98[a]). The concentration of $^{242}$Pu in the corrosion products domain after this time is maintained by $^{242}$Pu mass desorbing from the corrosion products. The concentration of $^{242}$Pu that is irreversibly sorbed onto iron oxyhydroxide colloids also keeps increasing until about 748,000 years and then declines slowly as iron oxyhydroxide colloids are transported out, predominantly by advection (Figure 7.7.1-97[a]). Because the concentration of $^{242}$Pu irreversibly sorbed onto iron oxyhydroxide colloids is not limited by solubility, it exceeds the dissolved concentration within a short period. Nevertheless, because the diffusion coefficient of colloids is calculated to be much smaller than the diffusion coefficient of dissolved plutonium (by a factor of about 700), the diffusive mass flux of $^{242}$Pu (aqueous), which is mostly dissolved mass, exceeds the advective mass flux of $^{242}$Pu irreversibly sorbed onto iron oxyhydroxide colloids (Figure 7.7.1-97[a]).

The mass released from the WP is passed into the UZ borehole that consists of dual porosity fracture and matrix media. The borehole is modeled using the GoldSim pipe element pathway, where only 1-D transport is considered. All of the mass released from the WP is placed in the fracture where it advects vertically downwards and diffuses laterally into the surrounding matrix medium. The volumetric flux of water applied to the fracture pathway is the same as that applied to the WP (about $8.7 \times 10^{-4}$ m$^3$/yr; equivalent to the percolation rate of about 26.9 mm/yr), which results in an average linear velocity of about 82 m/yr through the fracture medium, considering the fracture plan area of $4.2 \times 10^{-4}$ m$^2$, fracture saturation of 0.025, and no infill material in the fracture. Thus, for a species where fracture-matrix interaction is ignored, the travel time through the borehole length of 190 m should be less than 3 years.

The mass release of $^{99}$Tc from the borehole virtually overlays the mass release from the WP (Figure 7.7.1-99[a]), indicating negligible delay. This is expected as no retardation is modeled for $^{99}$Tc. Although fracture-matrix interaction could cause a minor delay in the $^{99}$Tc breakthrough time, those effects are not apparent because of large timesteps taken past 204,000 years. The long tail in the $^{99}$Tc release past 300,000 years, after most of the mass has been released, results from fracture-matrix interaction in the SZ where the mass is released back into the fractures from the matrix. The release rate from the SZ is comparable with that of the WP and UZ borehole releases early on, indicating fast transport through the SZ.

The release rates for the dissolved and reversibly sorbed $^{242}$Pu (denoted as aqueous) from the WP, UZ borehole, and SZ are shown on Figure 7.7.1-100[a]. The release rates out of the borehole are considerably smaller than the incoming release rates from the WP. This is attributed to retardation in the matrix once the mass diffuses into the matrix from the fractures. The $K_d$ for plutonium in the matrix is sampled to be about 115 mL/g (0.115 m$^3$/kg), which results in an effective retardation of about 1,550 (using the matrix bulk density of 1,980 kg/m$^3$ and matrix water content of 0.15). Because of the sorption, the dissolved concentration of $^{242}$Pu in the matrix medium is reduced, thereby increasing the diffusive gradient (and diffusive flux) from the fracture to the matrix, thus limiting the mass available for advective transport through the
fracture. The release rates out of the SZ are lower than that for the UZ borehole due to further retardation in the SZ volcanic and alluvium units.

The cumulative mass releases from the WP, UZ borehole, and SZ for the $^{99}$Tc, $^{242}$Pu (aqueous), and $^{242}$Pu (irreversibly sorbed on colloids) is shown on Figure 7.7.1-101[a]. The cumulative releases of $^{99}$Tc out of WP, UZ, and SZ virtually overlap, indicating negligible retardation. Similarly, negligible retardation is indicated for $^{242}$Pu (irreversibly sorbed on colloids) as the cumulative releases out of WP, UZ, and SZ virtually overlap. The fracture-matrix diffusive interaction for the mass irreversibly sorbed on colloids is not modeled in the UZ borehole and the SZ pathway due to the small diffusion coefficient of colloids. Thus, the mass of $^{242}$Pu irreversibly sorbed on colloids that is introduced into the UZ borehole fracture stays in the fracture and is advected out quickly. In the SZ, some retardation of the colloids due to interaction with the fracture surfaces is modeled but the affects are not apparent due to the large timesteps taken. In contrast, the cumulative mass released from the UZ borehole for $^{242}$Pu (aqueous) indicates that at the end of the simulation (one-million years), only a negligibly small fraction (<0.004) of the mass released from the WP is released out of the UZ borehole and, of the mass released from the UZ borehole, only about half is released out of the SZ. It is interesting to note that even though $^{242}$Pu (aqueous) release is higher out of the WP compared to the release of irreversibly sorbed $^{242}$Pu mass on colloids, due to retardation of $^{242}$Pu (aqueous) in the UZ borehole, the release of $^{242}$Pu irreversibly sorbed on colloids becomes relatively larger out of the UZ borehole.

The $^{242}$Pu mass irreversibly sorbed on colloids coming out of the UZ borehole is partitioned into a fast traveling fraction and a slow traveling fraction before being passed to the SZ. Almost all of the $^{242}$Pu mass irreversibly sorbed (99.8 percent) travels as a slow fraction in the SZ with some retardation of the colloid particles in the volcanic units and alluvium while the remaining travels unretarded as a fast fraction. All of the mass from the UZ borehole is passed into the SZ Source Region 1, consistent with the sampled aleatory uncertainty in this realization.

The mass release out of the SZ for $^{99}$Tc, $^{242}$Pu (aqueous), $^{242}$Pu (irreversible on colloids traveling slowly), and $^{242}$Pu (irreversible on colloids traveling fast) is shown on Figure 7.7.1-102[a]. The long tail in the $^{99}$Tc release past 300,000 years, after most of the mass has been released, results from fracture-matrix interaction in the SZ where the mass is released back into the fractures from the matrix. Following the depletion of $^{99}$Tc mass, the release rates from the slow traveling fraction of $^{242}$Pu mass irreversibly sorbed on colloids becomes dominant.

The SZ releases are converted into annual dose by taking the annual releases out of the SZ for each radionuclide, dissolving them in the 3,000 acre-ft of water (annual usage at RMEI as defined by the regulation) to compute the mass concentrations, converting the mass concentration into a concentration of radioactivity (in curies per liter of water), and then multiplying with the corresponding BDCFs computed for the modern-interglacial climate (present-day climate). The end result of this is Figure 7.7.1-94[a], where dose for total $^{242}$Pu (combined for mass in dissolved state, reversibly associated with colloids, and irreversibly associated with colloids) is shown.
Human Intrusion Modeling Case: Outlier

For the purpose of analyzing an outlier realization for the Human Intrusion Modeling Case, epistemic vector 181 was chosen as shown in Figure 7.7.1-103[a] because it has the highest annual dose between 300,000 and 800,000 years. Figure 7.7.1-104[a] displays the annual dose from 30 aleatory vectors associated with epistemic vector 181. The aleatory vector 15 (equivalent to GoldSim realization 5415) is chosen for further analysis due to its high dose. In this realization a CSNF WP, located in percolation subregion 3, is breached by the human intrusion and the mass is released through the UZ borehole pathway to the SZ source region 3.

The major dose contributing radionuclides for realization 5415 are shown in Figure 7.7.1-105[a]. Of these, the relative dose contribution from $^{242}$Pu is by far the highest from 300,000 years until the end of the simulation. Although $^{242}$Pu is also the dominant dose contributing radionuclide for realization 8309 described earlier (Figure 7.1.1-94[a]), its dose contribution relative to other radionuclides is much higher in realization 5415.

Figure 7.7.1-106[a] compares the dissolved $^{242}$Pu concentrations in the waste form and corrosion product domains along with the plutonium solubilities in the respective domains for realization 5415. Although plutonium solubilities and dissolved concentrations are similar to those for realization 8309, the concentrations of $^{242}$Pu associated irreversibly with iron oxyhydroxide colloids in the corrosion products domain is significantly higher. This is due to sampling higher iron oxyhydroxide colloid concentration (GoldSim epistemic uncertainty parameter Conc_Col_FeOx_SS_Sampled_a). For realization 5415, colloid concentration is sampled at 20.49 mg/L (at 98 percentile of the distribution) compared to a sampled value of 0.23 mg/L (at 64 percentile) for realization 8309. This two orders of magnitude difference in iron oxyhydroxide colloid concentration is proportional to the concentration of $^{242}$Pu associated irreversibly with iron oxyhydroxide colloids. This is the main reason for the outlier behavior observed at later times for this realization as the irreversibly sorbed mass is transported through the UZ and SZ. The volumetric flux through the WP and UZ borehole in realization 5415 ($= 7.6 \times 10^{-4}$ m$^3$/yr) is similar to that for realization 8309 ($= 8.7 \times 10^{-4}$ m$^3$/yr).

7.7.1.7[a] Seismic Ground Motion Modeling Case for 10,000 Years

This section presents an analysis of a single realization from the 9,000 realization base-case run performed for calculating the expected dose for the Seismic GM Modeling Case for the 10,000-year simulation duration (GoldSim filename: LA_v5.005_SM_009000_001.gsm; output DTN: MO0710ADTSPAWO.000 [DIRS 183752]). The expected annual dose is presented on Figure 7.7.1-107[a], where each of the 300 realizations represent expected annual dose for an epistemic uncertainty vector. The expected annual dose for each epistemic uncertainty vector is generated by taking an expectation over a sample of 30 aleatory uncertainty vectors that specify both the time of the seismic damage and the fractional damaged area of the WP.

The computational methodology for dose from the 10,000-year Seismic GM Modeling Case is different from that of the one-million-year case. Unlike the latter, where the sequence of seismic events are generated randomly and the damaged area of the WP is determined based on the computed PGV along with other parameters, the former is based on determining the dose response by specifying the WP damage time and the damaged area. This dose response function...
is used by Equation 6.1.2-22 of the parent document to compute the expected dose by taking the expectation over various damage areas and damage times. Because of this computational requirement, for each epistemic vector, the dose response functions for 30 aleatory uncertainty vectors are considered by specifying six discrete damage times (at 200; 1,000; 3,000; 6,000; 12,000; and 18,000 years) over each of the five fractional WP damage areas ($10^{-7}$, $10^{-6}$, $10^{-5}$, $10^{-4}$, and $10^{-3}$) (Table 6.6-3[a]). In addition, the consequences of seismic ground motion events are approximated by examining only the occurrence of SCC damage to CDSP WPs under intact DS without considering rockfall and without considering the effects of corrosion processes in thinning the WP OCB and DS. As a result, only diffusive releases from the CDSP WPs can occur. Furthermore, because the drift degradation is not considered, the thermal-hydrologic processes in the EBS remain the same as under nominal condition. For more details on the computational methodology, refer to Sections 6.1.2.4.4 and 7.3.2.6.1 of the parent document.

A single epistemic vector (out of a sample size of 300 epistemic vectors) is selected for further analysis in such a manner that the expected annual dose is broadly representative of the modeling case and similar in behavior to the mean annual dose curve. After consideration, epistemic vector 155 is chosen for further evaluation (Figure 7.7.1-107[a]). The thirty corresponding aleatory vectors (sampled for the given epistemic vector) are represented by GoldSim realizations 4621 through 4650 (Figure 7.7.1-108[a]). Of these, the eighth aleatory vector, which is equivalent to GoldSim realization 4628, is selected for further analysis (dashed red curve). In this aleatory vector, the seismic damage time is specified at 1,000 years and the fractional damaged area of the CDSP WP is specified at $10^{-5}$. The GoldSim file for realization 4628 is run twice to first save information for all the percolation subregions and then to specifically save EBS cell-pathway details related to percolation subregion 3 for the non-seeping environment (GoldSim filenames: LA_v5.005_SM_009000_008.gsm and LA_v5.005_SM_009000_009.gsm; output DTN: MO0801TSPAMVAC.000 [DIRS 185080]).

The total annual dose from realization 4628 is presented on Figure 7.7.1-109[a] along with the individual dose from major dose contributing radionuclides. The dominant radionuclides are $^{99}$Tc, $^{129}$I, $^{14}$C, $^{36}$Cl, and $^{79}$Se, with negligible contributions from remaining radionuclides. The annual dose increases rapidly following the WP damaging event at 1,000 years, reaching a maximum around 2,000 years and then declining gradually with time as the radionuclide mass is depleted. The bump noticeable around 2,000 years is a result of climate change from monsoonal to glacial-transition climate that occurs at 1,950 years. The dose behavior for $^{99}$Tc, $^{129}$I, $^{14}$C, and $^{36}$Cl is observed to be nearly identical to each other and results from their similar transport characteristics through the EBS, UZ, and SZ as these radionuclides are transported without any solubility control and without undergoing any sorption. The relative differences in dose among them are primarily due to their different masses in the inventory, decay rates, and BDCFs. The transport of $^{79}$Se is somewhat different from the rest as $^{79}$Se is retarded in the UZ and SZ despite having no solubility controlling mineral phase. Hence, for the purpose of describing the transport behavior of major dose contributing radionuclides, only $^{99}$Tc (the highest dose contributor among radionuclides that have similar transport characteristics) and $^{79}$Se are considered in the following discussion.

All CDSP WPs in all five percolation subregions fail at 1,000 years in this realization. The number of packages in a given percolation subregion is proportional to the repository area occupied by that percolation subregion. As a result, 40 percent of the WPs belong to percolation
subregion 3, 25 percent each to percolation subregions 2 and 4, and 5 percent each to percolation subregions 1 and 5. In each percolation subregion, the number of WPs is further distributed among seeping and non-seeping environments based on the seepage fraction for that percolation subregion. The number of failed CDSP WPs for all percolation subregions distinguished by seeping and non-seeping environments is shown on Figure 7.7.1-110[a]. Note that for a given percolation subregion, most of the WPs fall in the non-seeping environment due to small calculated seepage fraction. For example, the seepage fraction for percolation subregion 3 is about 0.33, so only 33 percent of the WPs assigned to percolation subregion 3 belong to the seeping environment, the remaining (67 percent) belong to the non-seeping environment. The seepage fraction for a given percolation subregion remains constant over the simulation duration and is based on the determination of fraction of seeping locations at 10,000 years in the given percolation subregion.

Since the DSs remains intact and only SCC on the CDSP WP surface due to vibratory ground motion is modeled, no advective transport of radionuclides can occur through the WP. The only release mechanism out of the WP is by diffusion along the diffusive pathways inside the WP and through the cracks on the WP OCB to the invert. Since the fractional damage area to the WP OCB, in this realization, is specified to be $10^{-5}$, it is equivalent to the diffusive area of $3.26 \times 10^{-4}$ m$^2$ (note that the outer surface area of the CDSP WP is set to be 32.6 m$^2$), which is applied only over the WP OCB thickness (computed to be 0.0301 m, the distance from outside the inner vessel to the outside of the OCB). Inside the WP the diffusive areas and diffusive lengths for the discretized transport domains are different and are described in Section 6.3.8 of the parent document.

The diffusive releases of $^{99}$Tc from the failed CDSP WPs for various percolation subregions (combined over seeping and non-seeping environments) are shown on Figure 7.7.1-111[a]. The diffusive release for percolation subregion 3 is the highest, as expected, due to greatest number of failed WPs among various percolation subregions. Although the number of failed WPs is the same among percolation subregions 2 and 4 and among percolation subregions 1 and 5, the relative peak releases are different because of higher seepage fractions for percolation subregion 4 (compared to 2) and 5 (compared to 1), leading to greater proportion of WPs being placed in a seeping environment. Diffusive release from a WP placed in a seeping environment, compared to a non-seeping environment, tends to be higher due to changed boundary conditions as drift seepage water flows through the invert and removes the mass. This has the effect of moving the zero concentration boundary closer to the WP, thereby increasing the concentration gradient from the WP to the invert. The diffusive releases of $^{79}$Se from failed CDSP WPs for various percolation subregions are similarly affected as $^{99}$Tc (Figure 7.7.1-112[a]). The magnitudes, however, are much smaller for $^{79}$Se due primarily to lower inventory mass per failed CDSP WP (about 12.5 g) compared to $^{99}$Tc (of about 960 g per failed CDSP WP), thus leading to lower concentrations in the WP and lower diffusive gradient. In addition, the free water diffusion coefficients among the two radionuclides are slightly different ($^{99}$Tc has a free water diffusion coefficient of $1.95 \times 10^{-9}$ m$^2$/s while that for $^{79}$Se is $1.04 \times 10^{-9}$ m$^2$/s), which could also cause minor differences in release.

Within percolation subregion 3, the diffusive and advective mass fluxes of $^{99}$Tc from the EBS are compared on Figure 7.7.1-113[a] for the seeping and non-seeping environments. Even though the releases from the WP are only diffusive, because of flow in the invert, the advective flux
from EBS is greater in the seeping environment. For the non-seeping environment, the diffusive flux from EBS is greater than the advective flux that results from imbition flow in the invert. Since the total mass flux for the non-seeping environment is greater than that for the seeping environment for percolation subregion 3 (due to larger number of failed WPs in the non-seeping environment), the results for the non-seeping environment are analyzed in more detail.

The dissolved concentrations of $^{99}$Tc out of the various transport domains in the EBS are shown in Figure 7.7.1-114[a]. The concentrations in the HLW and DSNF waste form subdomains and in the majority of the corrosion products domain overlap as a result of fast transport of $^{99}$Tc inside the WP due to the large diffusive areas modeled. As shown on Figure 7.7.1-114[a], the HLW glass is almost completely degraded by about 4,000 years. However, the $^{99}$Tc mass in the waste form and corrosion products domain is not fully depleted and the concentration declines gradually. This is attributed to the small diffusive area of $3.26 \times 10^{-4}$ m$^2$ applied to the transport cell representing the OCB thickness of 0.031 m within the corrosion products domain. This small diffusive area reduces the diffusive conductance across the WP OCB cell pathway and thus exerts a strong influence on the mass transport and concentrations in the surrounding cells that are part of the EBS transport finite difference network (Section 6.3.8 of the parent document). As a result, the concentration in the WP OCB cell is considerably reduced compared to the upstream waste form cells. The diffusive mass flux of $^{99}$Tc across various cell pathways is compared on Figure 7.7.1-115[a], which shows the reduction in diffusive flux across the WP OCB, thereby causing retention of appreciable mass in the WP for thousands of years following the breach. The diffusive release out of the upstream cell representing the corrosion products domain (except WP OCB cell) virtually overlaps that of the downstream WP OCB cell due to harmonic averaging of the cell properties for computing the diffusive conductance between the adjoining cells (see Equation 6.3.8-28 of the parent document). Since the diffusive area of the downstream WP OCB cell ($3.26 \times 10^{-4}$ m$^2$) is orders of magnitude smaller than that of the upstream cell ($29.7$ m$^2$; Section 6.3.8.2.3 of the parent document), the diffusive conductance between the two cells (within a finite difference network of cells) is controlled by the WP OCB cell.

The initial sharp increase in concentration noticeable on Figure 7.7.1-114[a] is due to the delayed onset of transport following the breach at 1,000 years as the relative humidity remains below the threshold value of 95 percent (required to initiate transport) until 1,080 years. As a result, almost 80 years of HLW mass is accumulated from degradation prior to the onset of release. Similarly, because all of the DSNF mass is degraded instantaneously following the WP breach, it is also all available for release after 1,080 years. The characteristics of diffusive release and concentrations for $^{79}$Se (not shown) are similar to that for $^{99}$Tc, except for the magnitudes, and also show the strong influence of reduced diffusive area of the WP OCB in controlling the mass flux out of the WP.

The mass released from the EBS (for each percolation subregion summed over the seeping and non-seeping environments) is passed to the UZ by partitioning the mass into the fracture and matrix nodes of the UZ transport model at the repository horizon. The fraction of $^{99}$Tc and $^{79}$Se mass that is passed to the fractures is shown on Figures 7.7.1-116[a] and 7.7.1-117[a]. In almost all percolation subregions (except for percolation subregion 1), the mass fraction going into the fracture (compared to the matrix) is greater than 0.5 initially following the breach and then reduces rapidly. This is because initially the mass flux from the seeping environment is greater.
than the non-seeping environment (due to increased concentration gradient between the WP and invert due to flow through the invert), which is predominantly passed into the UZ fracture continuum. Eventually, the mass contribution from the non-seeping environment increases (since more WPs are failed in the non-seeping environment) and more mass diffuses into the UZ matrix continuum due to the larger effective diffusive area connection between the matrix and the invert. After 4,000 years, steady state conditions are established once the HLW waste form is fully degraded and the release is controlled by the small diffusive area through the WP OCB. Among various percolation subregions, the fraction of mass released into the fracture is proportional to the seepage fraction. Thus, percolation subregion 5 (seepage fraction of 0.44) has relatively greater mass going into the fractures than percolation subregion 1 (seepage fraction of 0.16). As a result, the sharp increase noticed around 2,000 years due to climate change is most pronounced in percolation subregion 5 and least in percolation subregion 1.

The cumulative release over all percolation subregions from various transport domains from the engineered and natural barrier systems are shown on Figure 7.7.1-118[a] for $^{99}$Tc and Figure 7.7.1-119[a] for $^{79}$Se. For $^{99}$Tc, considerable delay in release occurs out of the WP compared to the release out of the waste form due to the small diffusive area in the WP OCB. Marginal delay is noticed in the invert early on (as shown by EBS release) due to transient conditions as the concentrations build up in the invert. After a few thousand years, the mass released from the EBS matches that released from the WP indicating the limited barrier capability of the invert for a non-sorbing radionuclide with no solubility control. The cumulative release curve for the UZ indicates considerable delay compared to the release from the EBS. This is attributed to the majority of the mass entering the UZ in the matrix nodes and undergoing slower transport. Due to fracture-matrix interaction, the mass that is released into the matrix continuum is transferred into the fracture continuum and quickly carried out via advection. Thus, although most of the mass enters the UZ through matrix nodes, most of it is released out of the fracture nodes at the UZ-SZ interface over the simulated time period. Despite this, only about 75 percent of the mass released from the EBS is released out of the UZ by 10,000 years, indicating appreciable UZ barrier capability in delaying the mass release once the mass enters the matrix. Some delay in the SZ is also observed due to the effects of longitudinal dispersion and fracture-matrix diffusive interaction; however, by 10,000 years, about 90 percent of the mass released from the UZ is released out of the SZ model boundary. The breakthrough curves for $^{99}$Tc in the SZ for all four regions are shown on Figure 7.7.1-120[a]. The breakthrough occurs quickly and, by 200 years following the mass input, almost half the mass gets released out of the SZ. The long tail that extends for thousands of years indicates a high degree of dispersion due to the fracture-matrix interaction as the mass that initially diffused into the SZ matrix moves back into the fracture and is eventually transported out.
The cumulative releases for $^{79}\text{Se}$ (Figure 7.7.1-119[a]) show similar behavior to $^{99}\text{Tc}$ for the release from the waste form, WP, and EBS. Due to the small diffusive area in the WP OCB, the release out of the WP is delayed and magnitude is reduced compared to the release out of the waste-form domain. However, in contrast to $^{99}\text{Tc}$, the transport of $^{79}\text{Se}$ is significantly retarded in the UZ and SZ. This is because of reversible sorption of $^{79}\text{Se}$ in the UZ and SZ volcanic matrix and SZ alluvium. The sampled $K_d$ for the UZ tuff matrix is about 9.3 mL/g (for zeolitic units), 7.4 mL/g (for devitrified units), and 4 mL/g (for vitric units). The sampled $K_d$ for the SZ matrix in the volcanic units is about 16.4 mL/g and that for the SZ alluvium is about 13.4 mL/g. The SZ alluvium $K_d$ is further modified by multiplying by the ratio of effective porosity (sampled value of 0.22) to the total porosity (0.3), thus leading to the effective SZ alluvium $K_d$ of 9.8 mL/g. In the UZ matrix, even with small sampled $K_d$ values, the retardation is significant as the concentration gradient from the matrix to the fracture is further reduced due to sorption in the matrix. By 10,000 years, only about 41 percent of the total mass released from the EBS is released out of the UZ. In the SZ, the delay is even more pronounced as only about 20 percent of the mass that enters from UZ is released out of the SZ model boundary by 10,000 years. Figure 7.7.1-120[a] shows the breakthrough curves from the four SZ regions indicating significant retardation for $^{79}\text{Se}$, with median delay of around 20,000 years. Compared to the transport of unretarded species such as $^{99}\text{Tc}$, the effective retardation factor of $^{79}\text{Se}$ in the SZ, for this realization, is about 100 (based on the ratio of median travel times of $^{79}\text{Se}$ to $^{99}\text{Tc}$).

The release rates out of the SZ model boundary for $^{99}\text{Tc}$ and $^{79}\text{Se}$ are shown on Figure 7.7.1-121[a] for realization 4628. The SZ releases are converted into annual dose by taking the annual releases out of the SZ for each radionuclide, dissolving them in the 3,000 acre-ft of water (annual usage at RMEI as defined by the regulation) to compute the mass concentrations, converting the mass concentration into concentration of radioactivity (in curies per liter of water), and then multiplying with the corresponding BDCFs computed for the modern-interglacial climate (present-day climate). The end result of this is Figure 7.7.1-109[a].

### 7.7.1.8[a] Summary of Single-Realization Analyses

The single-realization analyses of the seven modeling cases described above provide useful insights into interactions among several submodels under a variety of thermal, mechanical, chemical, and physical conditions in and around the repository. These analyses assist in understanding the coupling among the EBS, UZ, and SZ transport models when calculating annual dose to the RMEI in a given realization. Within each transport model domain, the interaction of various submodels (and their abstractions) under a given set of physicochemical conditions is described in detail, providing confidence that the submodels are coupled as intended and that their behaviors can be explained in a logical manner, leading to the dose calculations. In addition to explaining the interaction of submodels, the transport behaviors of major dose contributing radionuclides are also described and highlighted in the various modeling cases. For some modeling cases, outlier realization analysis is presented to highlight various processes or weighting factors that exert control on the magnitude of dose. In all cases, early releases following WP breach are dominated by non-sorbing and solubility-unlimited radionuclides, such as $^{99}\text{Tc}$ and $^{129}\text{I}$, whereas later releases are dominated by longer-lived, solubility-limited radionuclides that tend to sorb more strongly, such as $^{242}\text{Pu}$, $^{237}\text{Np}$, and $^{239}\text{Pu}$. 
7.7.2[a] Comparison with Simplified TSPA Analysis

A Simplified Analysis has been developed to evaluate repository performance utilizing simplified representations of the mathematical equations that describe radionuclide mass transfer rates. This analysis, called Simplified TSPA Analysis, is described in detail in Appendix L of the parent document. The analysis results are compared to the TSPA-LA Model results to generally corroborate the maximum dose levels. The Simplified TSPA Analysis has its bases in the process- and abstraction-level modeling captured in supporting analysis and model reports. Thus, it represents the same conceptualization of the repository system and its underlying technical bases to those of the TSPA-LA Model. However, detailed analysis, checking, and review activities identified an unintended inconsistency between the distribution coefficients ($K_d$) used for the TSW units in the UZ used in the simplified analysis (Appendix L of parent document) and those used in the TSPA-LA Model that was not previously documented in the parent document. The UZ $K_d$ distributions are set to the values for vitrified tuff in the simplified analysis (Appendix L of the parent document). These values are consistent with vitrified tuffs at the base of the TSW but inconsistent with the TSW units between the repository and the basal units, which make up much of the TSW below the repository, and are comprised of devitrified tuffs. The $K_d$ distributions for vitrified and devitrified tuff are similar for all radionuclides excluding $^{126}$Sn and $^{135}$Cs, which show significant differences (Table 6.3.9-2 and Table L-41 of the parent document). Since $^{126}$Sn and $^{135}$Cs are minor contributors to dose (Section 8.1[a]) despite the differences in the $K_d$ distributions, the basic results of the two models (i.e., dose over time and contribution to dose of dominant radionuclides) can be compared for individual modeling cases.

Models of the degradation of the engineered barriers were developed for the nominal, seismic ground motion, and igneous intrusion conditions. This was done to allow for comparisons with the modeling cases evaluated with the TSPA-LA Model. The Simplified TSPA Analysis is a different system level mathematical model, and the results can be used to generally corroborate the TSPA-LA Model v5.005 maximum dose.

7.7.2.1[a] Waste Package Early Failure Modeling Case

In the Simplified TSPA Analysis, a 500 realization simulation of the Waste Package EF Modeling Case was conducted over a 1,000,000-year period. A comparison of the Simplified TSPA Analysis results considering all realizations and the TSPA-LA Model results using v5.005 for this modeling case at 200,000 years; 400,000 years; 600,000 years; 800,000 years; and 1,000,000 years following repository closure is shown on Figure 7.7.2-3[a]. This comparison is identical to the results documented in Section 7.7.2.1 of the parent document and shows that the Simplified TSPA Analysis results in annual doses that are similar in magnitude to, but higher than, those of the TSPA-LA Model.

7.7.2.2[a] Nominal Modeling Case

The Nominal Modeling Case accounts for the WPs that fail under nominally expected conditions because of general corrosion and SCC and for the DSs that fail under nominally expected conditions because of general corrosion.
Figure 7.7.2-6[a] shows a comparison of the mean annual dose between the two models. The difference in the time that SCC begins between the Simplified TSPA Analysis and the TSPA-LA Model results in the difference in the annual dose histories. In a sense, the annual dose from the Simplified TSPA Analysis is translated outward in time by a few hundred thousand years.

This comparison is identical to the results documented in Section 7.7.2.2 of the parent document and shows that the general trend in the annual dose between the two models is very similar and the peak mean annual dose calculated using the Simplified TSPA Analysis is within approximately half of an order of magnitude as that calculated by the TSPA-LA Model.

7.7.2.3[a] Seismic Ground Motion Modeling Case

The Seismic GM Modeling Case evaluates repository performance for those WPs that fail due to the ground motion damage associated with the seismic event. This case begins with the Nominal Modeling Case discussed above and includes the effect of seismic events over a 1,000,000-year period. In the Simplified TSPA Analysis, the occurrence of seismic events is modeled using the approach presented in Section L2.1 of the parent document. The effects of seismic events on rockfall/drift degradation and seepage are modeled as presented in Sections L2.2 and L2.5 of the parent document, respectively. The effects of seismic ground motion on the performance of the DS and WP is modeled as presented in Sections L2.7.2 and L2.8.3 of the parent document, respectively.

The mean annual dose results for the Simplified TSPA Analysis are similar to those from the TSPA-LA Model. Figure 7.7.2-9[a] shows a comparison of the Simplified TSPA Analysis results and the TSPA-LA Model results for the Seismic GM Modeling Case at 200,000 years; 400,000 years; 600,000 years; 800,000 years; and 1,000,000 years following repository closure. There is generally a positive trend in the annual dose for the TSPA-LA Model results whereas the Simplified TSPA Analysis is variable with time. The two models show a similar peak mean annual dose; the Simplified TSPA Analysis is within approximately half an order of magnitude lower as that calculated by the TSPA-LA Model. However, the earlier peak dose in the Simplified TSPA Analysis reflects the differences in the sampling technique used in the Simplified TSPA Analysis and the lower rate of general corrosion results in 40 percent of the realizations having no WP failures over the 1,000,000-year simulation period, as documented in Section 7.7.2.3 of the parent document. Another notable difference occurs at 200,000 years. Figure 7.7.2-9[a] shows a significant reduction between the TSPA-LA Model v5.005 results and the Simplified TSPA Analysis. This is a result of differences between version 5.000 and 5.005 of the TSPA-LA Model as discussed in Section 7.3.1.5.6[a] of this addendum. Overall, for all other time periods the comparison presented in this addendum is nearly identical to the comparison of results documented in Section 7.7.2.3 of the parent document.

7.7.2.4[a] Igneous Intrusion Modeling Case

The Igneous Intrusion Modeling Case evaluates repository performance for the disruptive event where a volcanic dike intersects the repository. In the Simplified TSPA Analysis, a 1,000,000-year simulation was conducted where a single igneous intrusion event was assumed to randomly occur over the simulation period in each of 500 realizations. All WPs are assumed to be completely failed when the event occurs.
The mean annual dose results for the Simplified TSPA Analysis are similar to those from the TSPA-LA Model. Figure 7.7.2-12[a] shows a comparison of the Simplified TSPA Analysis results and the TSPA-LA Model v5.005 results for this modeling case at 200,000 years; 400,000 years; 600,000 years; 800,000 years; and 1,000,000 years following repository closure. There is generally a positive trend in the annual dose for the TSPA-LA Model results whereas the Simplified TSPA Analysis is variable with time. The results of the Simplified TSPA Analysis are similar in magnitude as those generated by the TSPA-LA Model with the Simplified TSPA Analysis yielding slightly higher mean annual doses. The comparison presented in this addendum differs slightly from the comparison of results documented in Section 7.7.2.4 of the parent document in that the results presented using version 5.005 of the TSPA-LA Model are generally lower than version 5.000 over all time periods after approximately 100,000 years. This difference can be attributed to the corrected distribution for the SZ longitudinal dispersivity as documented in Section 7.3.1.5.4[a] of this addendum.

7.7.3[a] Comparison with Electric Power Research Institute Analysis

No change.

7.7.3.1[a] Introduction and Purpose

This section gives a brief confirmation of the comparison between the EPRI TSPA Analysis and the TSPA-LA Model using v5.005 results. The purpose of this comparison is to confirm a summary presented in Section 7.7.3 of the parent document. The previous analysis showed the EPRI TSPA Analysis compared reasonably well with the TSPA-LA Model, and differences can be related to the different treatment of seepage, inventory, and EBS failure characteristics.

Section 7.7.3 of the parent document presents a comparison between the EPRI TSPA Analysis and the TSPA-LA Model considering the overall features of the dose history curves, together with evaluating the apparent differences between the two models. It is not necessary to reproduce that discussion in this addendum as the summary and conclusions will not change. Rather, only a brief comparison of the mean annual dose results using v5.005 is presented as confirmation of the comparison between the EPRI TSPA Analysis and the TSPA-LA Model.

7.7.3.2[a] Overview of the TSPA Models

No change.

7.7.3.3[a] Unsaturated Zone Flow

No change.

7.7.3.4[a] Engineered Barrier System Environment

No change.

7.7.3.5[a] Waste Package and Drip Shield Degradation

The EBS Corrosion Model is used in the EPRI TSPA Analysis to compute failure distributions for different components of the EBS, which comprise three versions for the nominal, seismic and
igneous scenarios. The EBS Corrosion Model accounts for various failure mechanisms and uncertain parameters that are sampled using Monte Carlo simulations to produce mean failure distribution curves for the DS, WP, and cladding. These mean failure distribution curves are used as input in the near-field model, which is described in greater detail in Appendix M. The current TSPA-LA Model does not take credit for cladding; that is, radionuclides can be released as soon as the WP starts to fail. The EPRI TSPA Analysis accounts for cladding failure for dripping and non-dripping conditions following WP failure.

In the EPRI TSPA Analysis, the computed failure distribution curves for the nominal scenario for the WP are shown on Figure 5-7 in Apted and Ross (2005 [DIRS 182229]), indicating onset of WP failures before 100,000 years. The EPRI TSPA Analysis only considers 8,160 CSNF WPs, of which 5,304 WPs fail after 1,000,000 years (Senger 2008 [DIRS 185124]). In the TSPA-LA Nominal Scenario Class, the probabilistic projections of WP breaches exhibit a few realizations with a SCC occurring before 100,000 years (Section 8.2.1[a]). However, as Figure 7.7.3-2[a] indicates, the bulk of the WP failure occurs after about 200,000 years with 6,256 WPs failed after 1,000,000 years.

As a confirmation of the comparison presented in Section 7.7.3.5 of the parent document, the mean WP and DS failure curves for the TSPA-LA Nominal Scenario Class are shown on Figure 7.7.3-2[a] using TSPA-LA Model v5.005. These results are identical to those presented on Figure 7.7.3-2 of the parent document.

7.7.3.6[a] Waste Form Degradation and Mobilization

No change.

7.7.3.7[a] Engineered Barrier System Flow and Transport

No change.

7.7.3.8[a] Unsaturated Zone Transport

No change.

7.7.3.9[a] Saturated Zone Transport

No change.

7.7.3.10[a] Biosphere

No change.

7.7.3.11[a] Mean Annual Dose Comparison—Nominal Case

The computed mean radionuclide doses for the EPRI nominal scenario is given on Figure 5-10 in Apted and Ross (2005 [DIRS 182229]). In comparison, the results from TSPA-LA Model v5.005 for the computed mean annual doses for the combined Nominal Scenario Modeling Case and the Waste Package EF Modeling Case are shown on Figure 7.7.3-3[a]. The results presented in this addendum are identical to the comparison of results documented in Section 7.7.3.11 of the parent document. These results corroborate the detailed analysis of the
comparison presented in Section 7.7.3.11 of the parent document. In general, the results presented in this addendum confirm the main features of the dose release curves for the EPRI nominal scenario compares reasonably well with the TSPA-LA Model. The differences can be related mostly to differences in seepage and in the different implementation of the inventory and EBS failure characteristics. This is partly due to the fact that the EPRI TSPA Analysis uses earlier analysis and/or model report results.

7.7.4[a] Performance Margin Analysis

The PMA calculations presented in Section 7.7.4 and Appendix C of the parent document paralleled those of the TSPA-LA Model (Section 8) but focused on scrutinizing the impact of select conservatisms embedded in the TSPA-LA Model components and submodels (utilized by the modeling cases to calculate annual doses). The PMA is intended to estimate the cumulative impact of the conservatisms in the TSPA-LA Model and, thereby, indicate the potential performance margin embedded in the TSPA-LA Model’s dose-risk projections. Thus, the PMA is an important validation activity supporting the TSPA-LA Model. The PMA evaluates and confirms the conservative nature of the TSPA-LA Model and it provides confidence that there are no non-conservatism remaining in the analysis. The results included in this addendum are used to update the conclusions of the PMA presented in the parent document.

7.7.4.1[a] Projections of the TSPA-LA Performance Margin

The objective of the PMA is to quantitatively evaluate the impact of the major explicit and implicit conservatisms in the TSPA-LA Model. This section provides a comparison of the total dose calculated by TSPA-LA Model v5.000, TSPA-LA Model v5.005, and the PMA presented in Appendix C of the parent document. This comparison confirms the conclusion of the analysis presented in Section 7.7.4.1 of the parent document.

Performance Margin in the Total Mean Annual Dose for 10,000 Years Postclosure

A comparison of the total mean annual dose history for the PMA and the TSPA-LA Model is shown on Figure 7.7.4-7a[a]. Figure 7.7.4-7a[a] shows that there is essentially no difference that exists between the mean annual dose estimates calculated by the two TSPA-LA Model versions for the first 10,000 years postclosure. Figure 7.7.4-7a[a] also shows that the following general observations about the performance margin projections for the first 10,000 years postclosure are the same as presented in Section 7.7.4 of the parent document:

- The PMA total mean annual doses are generally lower by nearly an order of magnitude over the first 10,000 years compared with the total mean annual dose from the TSPA-LA Model.
- The peak PMA total mean annual doses calculated over 10,000 years are lower by over an order of magnitude over the largest total mean annual dose from the TSPA-LA Model.
- Total mean annual doses calculated for 10,000 years are dominated by projected releases for the Igneous Intrusion Modeling Case (Appendix C, Figure C7-7, of the parent document).
Performance Margin in the Total Mean Annual Dose after 10,000 Years through the Period of Geologic Stability

A comparison of the total mean annual dose history for the PMA and the TSPA-LA Model is shown on Figure 7.7.4-7b[a]. For the 1,000,000-year simulation, the mean annual dose calculated by using TSPA-LA Model v5.005 is noticeably lower than TSPA-LA Model v5.000 from an approximate period of 120,000 years through about 300,000 years after postclosure (Figure 7.7.4-7b[a]). From this comparison plot, the following general observations can be drawn about the PMA out to 1,000,000 years postclosure:

- The PMA total mean annual doses are generally lower by nearly an order of magnitude over the first 100,000 years instead of 200,000 years as documented in the parent document and compared with the total mean annual dose from the TSPA-LA Model.

- The peak PMA total mean annual doses calculated over 1,000,000 years are lower by a factor of two over the largest total mean annual dose from the TSPA-LA Model as documented in the parent document.

The differences between the PMA results presented in the parent document to those in this addendum can be related mostly to an update to the implementation of the Seismic Ground Motion damage abstraction, as documented in Section P3 of Appendix P in the parent document. The probability of seismic damage is provided for two end-member states of the WP—one with intact internals and one with fully degraded internals. In TSPA-LA Model v5.000, once any WP is breached by a nominal process in a given percolation subregion (e.g., from first occurrence of stress corrosion cracks located on the outer lids), the probability of seismic damage is switched from the intact internals abstraction to the fully degraded internals abstraction, which increases the chance of seismic damage occurring while the DS is intact. This probability is then applied to all the WPs in the given percolation subregion, which is conservative, as most of the WPs have not yet failed by the nominal processes and should be using the intact internals damage probability. As a result, CSNF WPs fail earlier (Figure 8.1-5b of the parent document), beginning at approximately 150,000 years postclosure, and acquire greater damage area than expected, between approximately 200,000 and 300,000 years postclosure. The removal of this conservative implementation for seismic ground motion damage from v5.000 to v5.005 of the TSPA-LA Model results in fewer WPs damaged during a seismic event between approximately 200,000 and 300,000 years postclosure (Figure 8.1-5b[a]). This difference accounts for the smaller performance margin observed from approximately 200,000 to 300,000 years postclosure between the PMA and TSPA-LA Model v5.005 results presented in this addendum.

Scenario Specific Insights about the Performance Margin

Additional important insights about the performance margin can be gained by disaggregating the total mean annual dose into the total mean annual dose curves for the individual modeling cases and conducting a systematic evaluation of the effects of the changes incorporated into the PMA. This detailed analysis is included in Appendix C of the parent document; however, one notable change is documented in this addendum.
A comparison between the observations listed above for the PMA and the TSPA-LA Model results yields some notable differences. With regards to TSPA-LA Model v5.000 results, the Seismic GM Modeling Case dominates the total mean annual dose for the 10,000-year time period; whereas for 1,000,000 years, the Seismic GM and Igneous Intrusion Modeling Cases are the dominant contributors to the total mean annual dose to the RMEI (Figure 8.1-3, Section 8.1.1.2, of the parent document). However, in TSPA-LA Model v5.005 results while the Seismic GM Modeling Case still dominates the total mean annual dose for the 10,000-year time period, over the 1,000,000-year period the Igneous Intrusion Modeling Case dominates the total mean annual dose until approximately 700,000 years postclosure when the Seismic GM and Igneous Intrusion Modeling Cases contribute nearly equally to the total mean annual dose (Section 8.1.1.2[a]). In the PMA results, the Igneous Intrusion Modeling Case dominates the total mean annual dose for the time period of 10,000 years (Figure C7-7f of the parent document). For the time period after 10,000 years and through the period of geologic stability, the Igneous Intrusion Modeling Case dominates the total mean annual dose with a small contribution from the Seismic GM Modeling Case beginning around 225,000 years (Figure C7-8f of the parent document). These differences are primarily due to a lower incidence of WP failure (Appendix C6.8 and C7.2) and a reduction in the seismic induced WP SCC crack damage in the PMA Model (Appendix C6.8 and C7.2). The remaining cases combined have a negligible contribution for both the PMA and TSPA-LA Model total mean annual dose results.

7.7.4.2[a] Summary of the TSPA-LA Performance Margin

The results in this addendum confirm that the specified objectives of the PMA are met as follows:

1. The PMA results confirm that submodel conservatisms propagated through the TSPA-LA Model are also conservative with respect to the total system performance measures (e.g., total mean annual dose).

2. Relative to the TSPA-LA Model results, the peak PMA total mean annual dose is lower by over an order of magnitude for the 10,000-year time period and lower by a factor of two for the time period after 10,000 years.

3. The evaluated conservatisms did not introduce any inappropriate risk dilution in the TSPA Model results presented in support of the LA. This was demonstrated by the absence of higher peak mean annual doses relative to the TSPA-LA Model for the PMA results for both the probabilistic projections of the total dose histories and the projected total mean dose.

The assessment of the potential performance margin embedded in the TSPA-LA Model results is presented in detail in Appendix C of the parent document.

7.8[a] NATURAL ANALOGUES

No change.
7.9[a] TECHNICAL REVIEWS SUMMARY

No change.

7.10[a] SUMMARY OF MODEL CONFIDENCE BUILDING

The purpose of Section 7.10[a] is to summarize the additional validation activities documented in this addendum. Concluding remarks are presented in Section 7.10.10[a].

7.10.1[a] Validation Strategy

No change.

7.10.2[a] Code and Input Verification

For the results presented in this addendum, additional code and input verification testing was documented, including: (1) verification of the integrated system software (GoldSim) that is the software platform for the TSPA-LA Model used in this addendum, and (2) verification of model inputs from the TSPA Input Database. GoldSim V9.60.300 (STN: 10344-9.60-03 [DIRS 184387]) was qualified per IM-PRO-004. Additional submodels used in the Human Intrusion Scenario were verified. Coupling between the Human Intrusion submodels was examined by verifying that the information generated by one submodel is fed correctly to successive submodels and that this information does not exceed the applicable range of the successive submodel. The code and input verification was conducted to provide additional confidence in the software and the input used in the TSPA-LA Model and to comply with the requirements of SCI-PRO-006 Models, Section 6.3.2. In other words, these activities were conducted to verify that the computer codes and model inputs that originated from an outside source (analysis and/or model reports), or generated internally within the TSPA-LA Model, are implemented correctly.

The activities in Section 7.2 of the parent document and the additional work presented in Section 7.2[a] of this addendum demonstrate that the system software for TSPA-LA Model v5.005 is appropriate and valid, that input is correct and verified, that the internal transfer of information within the model is correct and within the valid range of successive submodels, and that submodels are valid per their respective source analysis and/or model reports. In other words, incorporation of information and submodels from other sources into TSPA-LA Model v5.005 has not altered the validity of the information or the submodels or both as demonstrated in the parent document for TSPA-LA Model v5.000.

7.10.3[a] Model Stability Testing

Demonstration of stability of TSPA-LA Model v5.005 is essential to validation and confidence building of the model results. As discussed in Section 7.3 of the parent document, the TSPA-LA Model computes mean annual dose in four steps: (1) selection of values for epistemic parameters and aleatory uncertainties; (2) numerically solving a complex, coupled system of differential equations describing radionuclide decay, flow, transport, and other physical processes; (3) integration over aleatory uncertainty, carried out either by quadrature or Monte Carlo techniques; and (4) integration over epistemic uncertainty, conducted by a Monte Carlo
technique. Section 7.3 of the parent document discusses the details of how the stability of the TSPA-LA Model is verified through implementation of the four steps during the TSPA-LA Model computations. TSPA-LA Model stability verification involved five different analyses: (1) statistical stability of mean annual dose, (2) numerical accuracy of expected annual dose, (3) temporal stability, (4) spatial stability, and (5) stability of a FEHM particle tracking model. A summary of each of these stability tests and their results obtained from them are provided in Section 7.10.3 of the parent document. Two additional analyses were presented in this addendum, one for statistical stability and one for temporal stability.

**Statistical Stability**

The TSPA-LA Model v5.005 changes are minor, the same LHS size (300) was used for TSPA-LA Model v5.000, and the uncertainty in total expected annual dose is driven by the same uncertain inputs. Thus, it is reasonable to conclude that TSPA-LA Model v5.005 also produces a statistically stable estimate of the total mean annual dose based upon the evaluation of the statistical stability presented in the parent document. However, an additional illustration of the accuracy of the estimate of the total mean annual dose for TSPA-LA Model v5.005, using a bootstrap sampling procedure to generate confidence intervals, is presented.

**Numerical Accuracy of Expected Annual Dose**

No change.

**Temporal Stability**

This addendum includes an update to the evaluation of temporal stability of the TSPA-LA Model Human Intrusion Scenario. This update was necessary due to the change in the timestepping scheme used in the Human Intrusion Scenario in TSPA-LA Model v5.005. The simulations were conducted by reducing the TSPA-LA Model timestep size to examine the timestep size sensitivity. The annual dose from the TSPA-LA Model calculations with different timestep sizes were compared graphically to determine the effect of refining the timesteps. The details of the approach and results are provided in Section 7.3.3 of the parent document. The results of this analysis show a better resolution using the base-case timestep scheme than previously documented in the parent document. The test results for the Human Intrusion Modeling Case confirm that the timestep scheme used for dose calculation in this modeling case is adequate.

In addition, a new evaluation of the temporal stability of the TSPA-LA Model Nominal Modeling Case is presented in Section 7.3.3.7[a]. The temporal discretization used to determine general corrosion rates is influential to the annual dose resulting from nominal corrosion processes. Simulation was conducted with shorter timesteps for the calculation of the crack growth rate, which removes the jumps in the number of WP failures by SCC, which in turn is reflected in the expected annual dose curves for the alternative scheme. However, this similarity in statistics for expected annual dose for the two timestep schemes indicates that the Nominal Modeling Case is sufficiently stable with respect to temporal discretization.
Spatial Stability
No change.

Stability of FEHM Particle Tracking Model
No change.

7.10.4[a] Uncertainty Characterization Review and Sensitivity Analyses
No change.

7.10.5[a] Surrogate Waste Form Validation
The analyses presented in Section 7.5 of the parent document and Section 7.5[a] of this addendum show that the use of surrogates to represent naval spent fuel is appropriate. Both analyses of NSNF show that mean annual dose from NSNF is bounded by that from the Zircaloy-clad CSNF surrogate.

7.10.6[a] Corroboration of Abstraction Results with Validated Process Models
No change.

7.10.7[a] Corroboration of Results with Auxiliary Analyses
The auxiliary analyses are an important aspect of determining whether the TSPA-LA Model is yielding reasonable results (e.g., that the model is producing the results that would be expected). Additional discussions of the results for some of the verification and validation testing activities presented in Section 7.7 of the parent document are presented in Section 7.7[a] for four different sets of auxiliary analyses: (1) single realization analysis (Section 7.7.1[a]), (2) updated comparison of the results of TSPA-LA Model v5.005 with a Simplified TSPA Analysis (Section 7.7.2[a]), (3) updated comparison of the results of TSPA-LA Model v5.005 with the TSPA independently developed by EPRI (Section 7.7.3[a]), and (4) updated PMA comparison to TSPA-LA Model v5.005 (Section 7.7.4[a]). A summary of the additional discussion included in this addendum is provided below.

Single Realization Analysis
The single realization analyses presented in the parent document and in Section 7.7.1[a] of this addendum comprise a comprehensive explanation detailing how the transport of key radionuclides is affected by coupling various submodels of the EBS, UZ, and SZ domains in the TSPA Model, following the WP failure under varying physical-chemical-thermal-mechanical conditions, and providing confidence that these model components are working as expected and the aggregate TSPA-LA Model results (in terms of dose) are reflective of the model components. Through examination and explanation of key aspects affecting the release of radionuclides, it is demonstrated that the TSPA-LA Model is functioning as intended and that the submodels are coupled correctly to yield the system level results. Repeating these analyses in this addendum
provides confidence that TSPA-LA Model v5.005 is functioning as designed and helps confirm the validation of the model.

The parent document includes single realization analyses of four modeling cases: (1) Waste Package EF Modeling Case (Section 7.7.1.1), (2) Drip Shield EF Modeling Case (Section 7.7.1.2), (3) Igneous Intrusion Modeling Case (Section 7.7.1.3), and (4) Seismic GM Modeling Case (1,000,000 years) (Section 7.7.1.4). Details of the analyses and ensuing results are repeated in this addendum and discussed in Sections 7.7.1.1[a] through 7.7.1.4[a]. Three additional modeling cases: (1) Nominal Modeling Case (Section 7.7.1.5), (2) Human Intrusion Modeling Case (Section 7.7.1.6), and (3) Seismic GM Modeling Case (10,000 years) (Section 7.7.1.7) are included in this addendum. The results confirm that the changes from TSPA-LA Model v5.000 to TSPA-LA Model v5.005 had little impact on the results presented using v5.000 and, therefore, support the demonstration of model validation and add to the confidence in the TSPA-LA Model results.

Comparison with Simplified TSPA Analysis

A comparison of the TSPA-LA Model results to a stand-alone Simplified TSPA Analysis was conducted and documented in Section 7.7.2 and Appendix L of the parent document. Section 7.7.2 of the parent document provides a detailed discussion on the comparative results for the individual modeling cases for the Simplified TSPA Analysis and the TSPA-LA Model, including the minor differences in the prominence of certain radionuclides and mean annual doses calculated by the two approaches. A comparison of the updated results presented in this addendum with the Simplified TSPA Analysis was provided in Section 7.7.2[a]. The results presented in Section 7.7.2[a] comparing the TSPA-LA Model v5.005 results and the Simplified TSPA Analysis corroborate the conclusions presented in the parent report.

Comparison with EPRI TSPA Analysis

A limited comparison of the EPRI TSPA Analysis results with those of TSPA-LA Model v5.005 is documented in this addendum. Detail of the similarities and differences between the EPRI TSPA Analysis and TSPA-LA Model v5.000 is discussed in Section 7.7.3 of the parent document with additional detail provided in Appendix M of the parent document. The results documented in Section 7.7.3[a] identify the general similarities as well as the differences between the results from the two models detailed in Section 7.7.3 of the parent document.

Performance Margin Analysis

A comparison of TSPA-LA Model v5.005 results with the PMA was conducted to confirm the quantitative evaluation of the differences in repository performance due to significant explicit and implicit conservatisms embedded in the TSPA-LA Model submodels documented in Section 7.7.4 and Appendix C of the parent document. The conservatisms were evaluated to (1) confirm that they are conservative with respect to the mean annual dose of the TSPA-LA Model; (2) quantify the extent to which they, individually and collectively, overestimate the projected annual dose; and (3) assess that the evaluated conservatisms did not introduce any inappropriate
risk dilution in the TSPA-LA Model results presented in support of the LA. The details of approach and results of the PMA are presented in Section 7.7.4 of the parent document with additional supporting material in Appendix C of the parent document. Summarizing here, the results show that the margin evaluated in the PMA as documented in the parent document are indeed conservative with respect to the total system performance measures (e.g., peak mean annual dose) as the largest doses calculated in the PMA for 10,000 years and 1,000,000 years are lower than the doses used in the compliance demonstration presented in Section 8[a] of this addendum. The additional analyses confirm that the largest calculated PMA mean annual doses are lower by over an order of magnitude and a factor of two over the largest mean annual dose relative to the TSPA-LA Model (Section 8[a]) for the time periods of 10,000 years and 1,000,000 years, respectively. Further, this PMA confirms that the significant conservatisms did not introduce risk dilution in the TSPA-LA Model results, as demonstrated by the absence of higher peak doses in the comparison of the projected total mean annual dose for the PMA relative to TSPA-LA Model v5.005. The differences in the relative contributions to the total mean annual dose from each of the scenario modeling cases between the PMA and the TSPA-LA Model indicate that the reduction in the selected conservative assumptions embedded in these TSPA-LA Model components provides a performance margin in the projected annual dose predictions presented in Section 8 of the parent document and Section 8[a] of this addendum.

7.10.8[a] Corroboration of Results with Natural Analogues

No change.

7.10.9[a] Technical Reviews Summary

No change.

7.10.10[a] Conclusions

The comparison of TSPA-LA Model v5.005 results to the validation activities that were presented in the parent document were conducted to verify that modifications to parameter values and submodel implementations detailed in Sections 4[a] and 6[a] of this addendum did not adversely affect the overall validation of the TSPA-LA Model. Additionally, only the validation and confidence building activities presented in the parent document that may have been affected by the changes from v5.000 to v5.005 have been updated in this addendum. Section 7[a] also includes additional discussion of the results for some of the verification and validation testing activities presented in the parent document that are used to enhance confidence in the TSPA-LA Model results. All results presented in this section utilized TSPA-LA Model v5.005 and confirmed that the updated model is within the range of validation previously documented in the parent document.

Changes were made to the TSPA-LA Model to address the issues presented in Appendix P of the parent document and to address unintended conservatisms in the TSPA-LA Model, as indicated in Appendix P[a] of this addendum. As documented in Appendix P of the parent document, and confirmed in the updated validation activities presented in this addendum, only Section P3 identified an issue in the TSPA-LA Model v5.000 that had the potential to significantly change the total expected annual dose results (Appendix P of the parent document). Although the
TSPA-LA Model v5.005 expected annual dose results confirm a significant decrease over the time period between approximately 100,000 to 300,000 years, the activities presented in Section 7 of the parent document, and the additional results documented in Section 7[a] of this addendum, confirm: (1) the GoldSim code functions as intended; (2) inputs were accurately implemented in the TSPA-LA Model; (3) the TSPA-LA Model is numerically, temporally, and spatially stable; and (4) the resultant dose calculations are appropriate for their intended use.
Figure 7.2-17[a]. Cumulative Releases of $^{129}\text{I}$, $^{237}\text{Np}$, and $^{233}\text{U}$ from the Human Intrusion Borehole Based on Simulations Considering and not Considering Matrix Diffusion.
Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0801TSPAADSA.000 [DIRS 185078].

Figure 7.3.1-14[a]. Stability of Human Intrusion Scenario: (a) Comparison of Expected Annual Dose for Three Replicates and (b) Confidence Interval around Mean Annual Dose
Figure 7.3.1-17[a]. Expected Annual Dose for 1,000,000 Years for the Nominal Modeling Case from (a) TSPA-LA Model v5.000 and (b) TSPA-LA Model v5.005
Total System Performance Assessment Model/Analysis for the License Application

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0709TSPAREGS.000 [DIRS 182976].

NOTE: Solid lines indicate TSPA-LA Model v5.000 and dashed lines indicate TSPA-LA Model v5.005.

Figure 7.3.1-18[a]. Comparison of Statistics for Expected Annual Dose in the Nominal Modeling Case between TSPA-LA Model v5.000 and TSPA-LA Model v5.005
Figure 7.3.1-19[a]. Comparison of Expected Annual Dose for Individual Sample Elements in the Nominal Modeling Case between TSPA-LA Model v5.000 and TSPA-LA Model v5.005 at (a) 400,000; (b) 600,000; (c) 800,000; and (d) 1,000,000 Years

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0709TSPAREGS.000 [DIRS 182976].
Figure 7.3.1-20[a]. Comparison of Statistics for Expected Annual Dose over 20,000 Years in the Drip Shield Early Failure Modeling Case between TSPA-LA Model v5.000 and TSPA-LA Model v5.005

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0709TSPAREGS.000 [DIRS 182976].
NOTE: Solid lines indicate TSPA-LA Model v5.000 and dashed lines indicate TSPA-LA Model v5.005.
Figure 7.3.1-21[a]. Comparison of Statistics for Expected Annual Dose over 1,000,000 Years in the Drip Shield Early Failure Modeling Case between TSPA-LA Model v5.000 and TSPA-LA Model v5.005

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0709TSPAREGS.000 [DIRS 182976].
NOTE: Solid lines indicate TSPA-LA Model v5.000 and dashed lines indicate TSPA-LA Model v5.005.
Figure 7.3.1-22[a]. Comparison of Expected Annual Dose for Individual Sample Elements in the Drip Shield Early Failure Modeling Case between TSPA-LA Model v5.000 and TSPA-LA Model v5.005 at (a) 1,000; (b) 3,000; (c) 5,000; and (d) 10,000 Years

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0709TSPAREGS.000 [DIRS 182976].
Total System Performance Assessment Model/Analysis for the License Application

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0709TSPAREGS.000 [DIRS 182976].

Figure 7.3.1-23[a]. Comparison of Expected Annual Dose for Individual Sample Elements in the Drip Shield Early Failure Modeling Case between TSPA-LA Model v5.000 and TSPA-LA Model v5.005 at (a) 100,000; (b) 200,000; (c) 600,000; and (d) 1,000,000 Years

F7.3-8[a] March 2008
Figure 7.3.1-24[a]. Comparison of Statistics for Expected Annual Dose over 20,000 Years in the Waste Package Early Failure Modeling Case between TSPA-LA Model v5.000 and TSPA-LA Model v5.005

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0709TSPAREGS.000 [DIRS 182976].

NOTE: Solid lines indicate TSPA-LA Model v5.000 and dashed lines indicate TSPA-LA Model v5.005.
Figure 7.3.1-25[a]. Comparison of Statistics for Expected Annual Dose over 1,000,000 Years in the Waste Package Early Failure Modeling Case between TSPA-LA Model v5.000 and TSPA-LA Model v5.005.
Total System Performance Assessment Model/Analysis for the License Application

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0709TSPAREGS.000 [DIRS 182976].

Figure 7.3.1-26[a]. Comparison of Expected Annual Dose for Individual Sample Elements in the Waste Package Early Failure Modeling Case between TSPA-LA Model v5.000 and TSPA-LA Model v5.005 at (a) 1,000; (b) 3,000; (c) 5,000; and (d) 10,000 Years

March 2008
Figure 7.3.1-27[a]. Comparison of Expected Annual Dose for Individual Sample Elements in the Waste Package Early Failure Modeling Case between TSPA-LA Model v5.000 and TSPA-LA Model v5.005 at (a) 100,000; (b) 200,000; (c) 600,000; and (d) 1,000,000 Years

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0709TSPAREGS.000 [DIRS 182976].
Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0709TSPAREGS.000 [DIRS 182976].

NOTE: Solid lines indicate TSPA-LA Model v5.000 and dashed lines indicate TSPA-LA Model v5.005.

Figure 7.3.1-28[a]. Comparison of Statistics for Expected Annual Dose over 20,000 Years in the Igneous Intrusion Modeling Case between TSPA-LA Model v5.000 and TSPA-LA Model v5.005
Figure 7.3.1-29(a). Comparison of Statistics for Expected Annual Dose over 1,000,000 Years in the Igneous Intrusion Modeling Case between TSPA-LA Model v5.000 and TSPA-LA Model v5.005.
Figure 7.3.1-30[a]. Comparison of Expected Annual Dose for Individual Sample Elements in the Igneous Intrusion Modeling Case between TSPA-LA Model v5.000 and TSPA-LA Model v5.005 at (a) 1,000; (b) 3,000; (c) 5,000; and (d) 10,000 Years
Total System Performance Assessment Model/Analysis for the License Application

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0709TSPAREGS.000 [DIRS 182976].

Figure 7.3.1-31[a]. Comparison of Expected Annual Dose for Individual Sample Elements in the Igneous Intrusion Modeling Case between TSPA-LA Model v5.000 and TSPA-LA Model v5.005 at (a) 100,000; (b) 200,000; (c) 600,000; and (d) 1,000,000 Years
Figure 7.3.1-32[a]. Comparison of Statistics for Expected Annual Dose over 20,000 Years in the Seismic Ground Motion Modeling Case between TSPA-LA Model v5.000 and TSPA-LA Model v5.005.
Figure 7.3.1-33[a]. Comparison of Expected Annual Dose for Individual Sample Elements in the Seismic Ground Motion Modeling Case between TSPA-LA Model v5.000 and TSPA-LA Model v5.005 at (a) 1,000; (b) 3,000; (c) 5,000; and (d) 10,000 Years

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0709TSPAREGS.000 [DIRS 182976].
Figure 7.3.1-34[a]. Expected Annual Dose for 1,000,000 Years for the Seismic Ground Motion Modeling Case from (a) TSPA-LA Model v5.000 and (b) TSPA-LA Model v5.005

Source: Output DTNs: MO0709TSPAREGS.000 [DIRS 182976]; and MO0710ADTSPAWO.000 [DIRS 183752].
Comparison of Statistics for Expected Annual Dose over 1,000,000 Years in the Seismic Ground Motion Modeling Case between TSPA-LA Model v5.000 and TSPA-LA Model v5.005
Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0709TSPAREGS.000 [DIRS 182976].

Figure 7.3.1-36[a]. Comparison of Expected Annual Dose for Individual Sample Elements in the Seismic Ground Motion Modeling Case between TSPA-LA Model v5.000 and TSPA-LA Model v5.005 at (a) 100,000; (b) 200,000; (c) 600,000; and (d) 1,000,000 Years
Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0709TSPAREGS.000 [DIRS 182976].
NOTE: Solid lines indicate TSPA-LA Model v5.000 and dashed lines indicate TSPA-LA Model v5.005.

Figure 7.3.1-37[a]. Comparison of Statistics for Expected Annual Dose over 20,000 Years in the Seismic Fault Displacement Modeling Case between TSPA-LA Model v5.000 and TSPA-LA Model v5.005.
Figure 7.3.1-38[a]. Comparison of Statistics for Expected Annual Dose over 1,000,000 Years in the Seismic Fault Displacement Modeling Case between TSPA-LA Model v5.000 and TSPA-LA Model v5.005
Figure 7.3.1-39[a]. Comparison of Expected Annual Dose for Individual Sample Elements in the Seismic Fault Displacement Modeling Case between TSPA-LA Model v5.000 and TSPA-LA Model v5.005 at (a) 1,000; (b) 3,000; (c) 5,000; and (d) 10,000 Years.

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0709TSPAREGS.000 [DIRS 182976].
Figure 7.3.1-40[a]. Comparison of Expected Annual Dose for Individual Sample Elements in the Seismic Fault Displacement Modeling Case between TSPA-LA Model v5.000 and TSPA-LA Model v5.005 at (a) 100,000; (b) 200,000; (c) 600,000; and (d) 1,000,000 Years

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0709TSPAREGS.000 [DIRS 182976].
Figure 7.3.1-41[a]. Total Expected Annual Dose for 10,000 Years from (a) TSPA-LA Model v5.000 and (b) TSPA-LA Model v5.005

Source: Output DTNs: MO0079TSPAREGS.000 [DIRS 182976]; and MO00710ADTSPAWO.000 [DIRS 183752].

MDL-WIS-PA-000005 REV 00 AD01 F7.3-26[a] March 2008
Figure 7.3.1-42[a]. Comparison of Statistics for Total Expected Annual Dose over 20,000 Years between TSPA-LA Model v5.000 and TSPA-LA Model v5.005.
Figure 7.3.1-43[a]. Comparison of Total Expected Annual Dose for Individual Sample Elements between TSPA-LA Model v5.000 and TSPA-LA Model v5.005 at (a) 1,000; (b) 3,000; (c) 5,000; and (d) 10,000 Years

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0709TSPAREGS.000 [DIRS 182976].
Figure 7.3.1-44[a]. Total Expected Annual Dose for 1,000,000 Years from (a) TSPA-LA Model v5.000 and (b) TSPA-LA Model v5.005

Source: Output DTNs: MO0709TSPAREGS.000 [DIRS 182976]; and MO0710ADTSPAWO.000 [DIRS 183752].
Figure 7.3.1-45[a]. Comparison of Statistics for Total Expected Annual Dose over 1,000,000 Years between TSPA-LA Model v5.000 and TSPA-LA Model v5.005.

Source:  Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0709TSPAREGS.000 [DIRS 182976].

NOTE:  Solid lines indicate TSPA-LA Model v5.000 and dashed lines indicate TSPA-LA Model v5.005.
Figure 7.3.1-46[a]. Comparison of Total Expected Annual Dose for Individual Sample Elements between TSPA-LA Model v5.000 and TSPA-LA Model v5.005 at (a) 100,000; (b) 200,000; (c) 600,000; and (d) 1,000,000 Years

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0709TSPAREGS.000 [DIRS 182976].
Figure 7.3.1-47[a]. Confidence Interval for Total Mean Annual Dose for 20,000 Years for (a) TSPA-LA Model v5.000 and (b) TSPA-LA Model v5.005 Computed with the Bootstrap Technique
Total System Performance Assessment Model/Analysis for the License Application

Source: Output DTN: MO0801TSPAADSA.000 [DIRS 185078].

Figure 7.3.1-48[a]. Confidence Interval for Total Mean Annual Dose for 1,000,000 Years for (a) TSPA-LA Model v5.000 and (b) TSPA-LA Model v5.005 Computed with the Bootstrap Technique.
Total System Performance Assessment Model/Analysis for the License Application

Figure 7.3.3-10[a]. Expected Annual Dose from a Human Intrusion at 200,000 Years for Two Timestep Schemes

Source: Output DTNs: MO0710ADTSPAWO.000, File: v5.005_HI_009000_000 [DIRS 183752], for Base Case; and MO0801TSPAADSA.000, File: v5.005_HI_009000_001 [DIRS 185078], for Alternates.
Source: Output DTNs: MO0710ADTSPAWO.000, File: v5.005_HI_009000_000 [DIRS 183752], for Base Case; and MO0801TSPAADSA.000, File: v5.005_HI_009000_001 [DIRS 185078], for Alternates.

Figure 7.3.3-11[a]. Detail of Expected Annual Dose from a Human Intrusion at 200,000 Years for Two Timestep Schemes
Total System Performance Assessment Model/Analysis for the License Application

Figure 7.3.3-12[a]. Expected Annual Dose for 1,000,000 Years for the Nominal Modeling Case from (a) TSPA-LA Model v5.005 and (b) Alternative Timestep Scheme

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0801TSPAWPDS.000 [DIRS 185077].
Figure 7.3.3-13[a]. Expected Annual Dose Statistics for 1,000,000 Years for the Nominal Modeling Case Using Two Timestep Schemes
Figure 7.5-4[a]. Comparison of Mean Annual Dose for a Single CSNF WP and a Single Waste Package with a Naval Source Term for the Drip Shield Early Failure Modeling Case
Figure 7.5-5[a]. Comparison of Mean Annual Dose for a Single CSNF WP and Single WP with a Naval Source Term for the Igneous Intrusion Modeling Case
Total System Performance Assessment Model/Analysis for the License Application

Figure 7.7.1-1[a]. Expected Annual Dose from 300 Epistemic Vectors, Along with their Quantiles and Expected Dose from Epistemic Vector 281 for the Waste Package Early Failure Modeling Case for 1,000,000 Years after Repository Closure: (a) Linear Time and (b) Log Time

Source: Output DTN: MO0710ADTSPAWO.000 [DIRS 183752].
Figure 7.7.1-2[a]. Annual Dose from Realizations 5601 through 5620 of the Waste Package Early Failure Modeling Case for 1,000,000 Years after Repository Closure

Source: Output DTN: MO0710ADTSPAWO.000 [DIRS 183752].
Figure 7.7.1-3[a]. Major Radionuclide Contributors to Mean Annual Dose for the Waste Package Early Failure Modeling Case for 1,000,000 Years after Repository Closure

Source: Output DTN: MO0710ADTSPAWO.000 [DIRS 183752].
Figure 7.7.1-4[a]. Major Radionuclide Contributors to Annual Dose for Realization 5608 of the Waste Package Early Failure Modeling Case for 1,000,000 Years after Repository Closure.
NOTE: In the (b) plot, the mass of plutonium dissolved and reversibly associated with colloids is denoted as aqueous.

Figure 7.7.1-5[a]. (a) Release Rates of Technetium from the Waste Form, EBS, Unsaturated Zone, and Saturated Zone for Realization 5608 and (b) Saturated Zone Breakthrough Curves of Technetium and Plutonium for Epistemic Uncertainty Vector 281 of the Waste Package Early Failure Modeling Case for 1,000,000 Years after Repository Closure
In the (a) plot, the release rate does not include the mass released as irreversibly associated with colloids.

Figure 7.7.1-6[a]. (a) Release Rates and (b) Concentration of $^{239}$Pu for Realization 5608 of the Waste Package Early Failure Modeling Case for 1,000,000 Years after Repository Closure
Figure 7.7.1-7[a]. (a) Dissolved Concentrations of Plutonium in the CSNF Waste Form Domain for Realization 5608 and (b) CSNF Waste Form Domain Chemistry for Realization 5608 of the Waste Package Early Failure Modeling Case for 1,000,000 Years after Repository Closure.
Figure 7.7.1-8[a]. Corrosion Product Sorption Coefficients ($K_d$) and In-package pH for Realization 5608 of the Waste Package Early Failure Modeling Case for 1,000,000 Years after Repository Closure.
NOTE: In the (a) plot, the release rate does not include the mass released as irreversibly associated with colloids.

Figure 7.7.1-9[a]. (a) Release Rates and (b) Concentration of $^{242}$Pu for Realization 5608 of the Waste Package Early Failure Modeling Case for 1,000,000 Years after Repository Closure
Source: Output DTN: MO0801TSPAMVAC.000 [DIRS 185080].

Figure 7.7.1-10[a]. Major Radionuclide Contributors to Annual Dose for Realization 5618 of the Waste Package Early Failure Modeling Case for 1,000,000 Years after Repository Closure
Figure 7.7.1-11[a]. Cumulative Release from HLW and DSNF Waste Forms for Realization 5618 of the Waste Package Early Failure Modeling Case for 1,000,000 Years after Repository Closure.
Figure 7.7.1-12[a]. Release Rates of $^{99}$Tc from the Waste Form, Invert, Unsaturated Zone, and Saturated Zone for Realization 5618 of the Waste Package Early Failure Modeling Case for 1,000,000 Years after Repository Closure
Source: Output DTN: MO0801TSPAMVAC.000 [DIRS 185080].

NOTE: In the (a) plot, the release rate does not include the mass released as irreversibly associated with colloids.

Figure 7.7.1-13[a]. (a) Release Rates and (b) Concentration of $^{239}$Pu for Realization 5618 of the Waste Package Early Failure Modeling Case for 1,000,000 Years after Repository Closure.
Figure 7.7.1-14(a). (a) Dissolved Concentrations of Plutonium in the High-Level Radioactive Waste Domain and (b) DSNF Waste Form Domain Chemistry for Realization 5618 of the Waste Package Early Failure Modeling Case for 1,000,000 Years after Repository Closure

Source: Output DTN: MO0801TSPAMVAC.000 [DIRS 185080].
Figure 7.7.1-15[a]. (a) Release Rates and (b) Concentration of $^{242}$Pu for Realization 5618 of the Waste Package Early Failure Modeling Case for 1,000,000 Years after Repository Closure
Figure 7.7.1-16[a]. Expected Annual Dose from 300 Epistemic Uncertainty Vectors, Along with their Quantiles and Expected Dose from Epistemic Uncertainty Vector 247 for the Waste Package Early Failure Modeling Case for 1,000,000 Years after Repository Closure: (a) Linear Time and (b) Log Time.
Figure 7.7.1-17[a]. Annual Dose from Realizations 4921 through 4940 of the Waste Package Early Failure Modeling Case for 1,000,000 Years after Repository Closure
Figure 7.7.1-18[a]. Major Radionuclide Dose Contributors for Realization (a) 4930 and (b) 4940 of the Waste Package Early Failure Modeling Case for 1,000,000 Years after Repository Closure

Source: Output DTN: MO0801TSPAMVC.000 [DIRS 185080].
Plutonium dissolved and reversibly associated with colloids is denoted as aqueous.

Figure 7.7.1-19[a]. Saturated Zone Breakthrough Curves for Epistemic Uncertainty Vector 247 of the Waste Package Early Failure Modeling Case for 1,000,000 Years after Repository Closure.
Figure 7.7.1-20[a]. Concentration of (a) $^{239}$Pu and (b) $^{242}$Pu for Realization 4930 of the Waste Package Early Failure Modeling Case for 1,000,000 Years after Repository Closure

Source: Output DTN: MO0801TSPAMVC.000 [DIRS 185080].
Figure 7.7.1-21[a]. Expected Annual Dose from 300 Epistemic Uncertainty Vectors, Along with their Quantiles and Expected Dose from Epistemic Uncertainty Vector 228 for the Drip Shield Early Failure Modeling Case for 1,000,000 Years after Repository Closure.
Figure 7.7.1-22[a]. Major Radionuclide Contributors to Mean Annual Dose for the Drip Shield Early Failure Modeling Case for 1,000,000 Years after Repository Closure

Source: Output DTN: MO0710ADTSPAWO.000 [DIRS 183752].
Figure 7.7.1-23[a]. Annual Dose for Ten Aleatory Uncertainty Realizations (Vectors) for the Epistemic Uncertainty Vector 228 of the Drip Shield Early Failure Modeling Case for 1,000,000 Years after Repository Closure
Plutonium dissolved and reversibly associated with colloids is denoted as aqueous.

Figure 7.7.1-24[a]. (a) Annual Dose along with Major Radionuclide Dose Contributors and (b) Contribution of $^{239}\text{Pu}$ and $^{242}\text{Pu}$ (Aqueous and Associated Irreversibly with Colloids) for Realization 2278 of the Drip Shield Early Failure Modeling Case for 1,000,000 Years after Repository Closure
Figure 7.7.1-25[a]. EBS Release Rates of $^{99m}$Tc Along with Waste Package Temperatures for the Two Selected Realizations (2273 and 2278) of the Drip Shield Early Failure Modeling Case for 1,000,000 Years after Repository Closure

Source: Output DTN: MO0801TSPAMVAC.000 [DIRS 185080].
Source: Output DTN: MO0801TSPAMVAC.000 [DIRS 185080].

Figure 7.7.1-26[a]. Flow Rate Incident on the Waste Package Showing the Effects of Drift Wall Condensation and Climate Change for the Two Selected Realizations (2273 and 2278) of the Drip Shield Early Failure Modeling Case for 1,000,000 Years after Repository Closure
Figure 7.7.1-27[a]. Fraction of CSNF and HLW Glass Waste Form Degraded for the Two Selected Realizations (2273 and 2278) of the Drip Shield Early Failure Modeling Case for 1,000,000 Years after Repository Closure.
GoldSim realization 2278 represents a CDSP WP in percolation subregion 3. Plutonium dissolved and reversibly associated with colloids is denoted as aqueous.

Figure 7.7.1-28[a]. Fraction of EBS Mass Flux Released into Unsaturated Zone Fractures for Selected Radionuclides for Realization 2278 of the Drip Shield Early Failure Modeling Case for 1,000,000 Years after Repository Closure
For $^{242}$Pu, the release includes the mass released in the dissolved state and reversibly associated with colloids.

Figure 7.7.1-29[a]. Cumulative Mass Release of $^{99}$Tc and $^{242}$Pu from the EBS, Unsaturated Zone, and Saturated Zone for Realization 2278 of the Drip Shield Early Failure Modeling Case for 1,000,000 Years after Repository Closure
Figure 7.7.1-30[a]. Expected Annual Dose and Epistemic Uncertainty Vector 244 for the Drip Shield Early Failure Modeling Case for 1,000,000 Years after Repository Closure

Source: Output DTN: MO0710ADTSPAWO.000 [DIRS 183752].

Expected Annual Dose (nrem) vs. Time (years)

- Mean
- Median
- 95th Percentile
- 5th Percentile
- Epistemic Vector 244
Figure 7.7.1-31[a]. Ten Aleatory Uncertainty Vectors for the Epistemic Uncertainty Vector 244 of the Drip Shield Early Failure Modeling Case for 1,000,000 Years after Repository Closure.
NOTE: Radionuclides dissolved and reversibly associated with colloids are denoted as aqueous.

Figure 7.7.1-32[a]. Major Radionuclide Dose Contributors to Annual Dose for Realization 2433 of the Drip Shield Early Failure Modeling Case for 1,000,000 Years after Repository Closure.
Seepage Fraction Statistics and Seepage Fraction for Realization 2433 for the Drip Shield Early Failure Modeling Case for 1,000,000 Years after Repository Closure

Source: Output DTN: MO0710ADTSPAWO.000 [DIRS 183752].

Figure 7.7.1-33[a]. Seepage Fraction Statistics and Seepage Fraction for Realization 2433 for the Drip Shield Early Failure Modeling Case for 1,000,000 Years after Repository Closure
Figure 7.7.1-34[a]. Seepage Rate Statistics and Seepage Rate for Realization 2433 for the Drip Shield Early Failure Modeling Case for 1,000,000 Years after Repository Closure

Source: Output DTN: MO0710ADTSPAWO.000 [DIRS 183752].

Figure 7.7.1-34[a]. Seepage Rate Statistics and Seepage Rate for Realization 2433 for the Drip Shield Early Failure Modeling Case for 1,000,000 Years after Repository Closure
Source: Output DTN: MO0801TSPAMVAC.000 [DIRS 185080].

NOTE: For plutonium, release includes the mass released in the dissolved state and reversibly associated with colloids.

Figure 7.7.1-35[a]. Saturated Zone Breakthrough Curves for Plutonium and Neptunium for All Four Saturated Zone Regions for Realization 2433 of the Drip Shield Early Failure Modeling Case for 1,000,000 Years after Repository Closure
Figure 7.7.1-36[a]. Major Radionuclide Contributors to Mean Annual Dose for the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure

Source: Output DTN: MO0710ADTSPAWO.000 [DIRS 183752].
Expected Annual Dose from the 300 Epistemic Uncertainty Vectors Along with their Quantiles and Expected Dose from Epistemic Uncertainty Vector 286 for the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure

Source: Output DTN: MO0710ADTSPAWO.000 [DIRS 183752].

Figure 7.7.1-37[a]. Expected Annual Dose from the 300 Epistemic Uncertainty Vectors Along with their Quantiles and Expected Dose from Epistemic Uncertainty Vector 286 for the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure.
Figure 7.7.1-38[a]. Annual Dose for Realizations 2851 through 2860 (representing Epistemic Uncertainty Vector 286) along with Selected Realization 2855 of the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure
Figure 7.7.1-39[a]. Major Radionuclide Dose Contributors to Annual Dose for Realization 2855 of the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure

Source: Output DTN: MO0801TSPAMVAC.000 [DIRS 185080].
Figure 7.7.1-40[a]. Dissolved Concentrations and Solubility Limits of Neptunium, Plutonium, Uranium, and Radium in the CSNF Waste Form Domain for Percolation Subregion 3 Seeping Environment for Realization 2855 of the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure

Source: Output DTN: MO0801TSPAMVAC.000 [DIRS 185080].
Figure 7.7.1-41[a]. In-Package pH and $P_{CO_2}$ in the Waste Form Domain for Percolation Subregion 3 Seeping Environment for Realization 2855 of the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure
NOTE: Plutonium dissolved and reversibly associated with colloids is denoted as aqueous.

Figure 7.7.1-42[a]. Release Rate of Major Radionuclides from all Waste Packages for Realization 2855 of the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure.
Total System Performance Assessment Model/Analysis for the License Application

Figure 7.7.1-43[a]. Advevtive and Diffusive Release Rates of Major Radionuclides (Dissolved and Reversibly Associated with Colloids) from the CSNF WPs for Realization 2855 of the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure

Source: Output DTN: MO0801TSPAMVAC.000 [DIRS 185080].
Figure 7.7.1-44[a]. Total Dissolved Concentrations and Solubility Limits of Neptunium, Plutonium, Uranium, and Radium in the Corrosion Products Domain of CSNF WPs Located in Percolation Subregion 3 Seeping Environment for Realization 2855 of the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure

Source: Output DTN: MO0801TSPAMVAC.000 [DIRS 185080].
Cumulative Releases of: (a) $^{237}\text{Np}$, (b) $^{234}\text{U}$, (c) $^{242}\text{Pu}$ (Dissolved and Reversibly Associated with Colloids), and (d) $^{226}\text{Ra}$ from the EBS, Unsaturated Zone, and Saturated Zone for Realization 2855 of the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure
Figure 7.7.1-45[a]. Cumulative Releases of: (a) $^{237}$Np, (b) $^{234}$U, (c) $^{242}$Pu (Dissolved and Reversibly Associated with Colloids), and (d) $^{226}$Ra from the EBS, Unsaturated Zone, and Saturated Zone for Realization 2855 of the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure (Continued)

Source: Output DTN: MO0801TSPAMVAC.000 [DIRS 185080].
Source: Output DTN: MO0801TSPAMVAC.000 [DIRS 185080].

NOTE: The saturated zone concentrations shown on this figure are obtained by dividing the annual releases of radionuclides from the saturated zone by the 3,000 acre-ft/yr annual water usage, as required by regulations.

Figure 7.7.1-46[a]. Concentrations of Major Radionuclides (Dissolved and Reversibly Associated with Colloids) at the RMEI Location for Realization 2855 of the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure
Figure 7.7.1-47[a]. Expected Annual Dose from the 300 Epistemic Uncertainty Vectors along with their Quantiles and Expected Dose from Epistemic Uncertainty Vector 20 for the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure.
Figure 7.7.1-48[a]. Annual Dose from the Ten Aleatory Vectors Associated with the Epistemic Uncertainty Vector 20 for the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure.
Figure 7.7.1-49[a]. Major Radionuclide Dose Contributors to Annual Dose for Realization 191 of the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure
Source: Output DTN: MO0801TSPAMVAC.000 [DIRS 185080].

Figure 7.7.1-50[a]. Climate Status and Water Flux for Realization 191 of the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure
Figure 7.7.1-51[a]. Solubility and Dissolved Concentrations of Plutonium and Uranium within the CSNF Domain for Realization 191 of the Igneous Intrusion Modeling Case for 1,000,000 Years after Repository Closure
Figure 7.7.1-52[a]. Expected Annual Dose from the 300 Epistemic Uncertainty Vectors Along With their Quantiles and Expected Dose from Epistemic Uncertainty Vector 155 for the Seismic Ground Motion Modeling Case for 1,000,000 Years after Repository Closure
Source: Output DTN: MO0710ADTSPAWO.000 [DIRS 183752].

NOTES: The dashed line is the expected annual dose for epistemic uncertainty vector 155 by taking expectation over the thirty aleatory vectors. The solid red line is the annual dose from aleatory vector 21, which is equivalent to GoldSim realization 4641.

Figure 7.7.1-53[a]. Annual Dose from the Thirty Aleatory Vectors (Seismic Event Sequences) Associated with the Epistemic Uncertainty Vector 155 for the Seismic Ground Motion Modeling Case for 1,000,000 Years after Repository Closure
Figure 7.7.1-54[a]. Annual Dose along with Major Radionuclide Dose Contributors for Realization 4641 of the Seismic Ground Motion Modeling Case for 1,000,000 Years after Repository Closure

Source: Output DTN: MO0710ADTSPAWO.000 [DIRS 183752].
Figure 7.7.1-55[a]. Number of Seismic Events and the Peak Ground Velocities for Realization 4641 of the Seismic Ground Motion Modeling Case for 1,000,000 Years after Repository Closure

Source: Output DTN: MO0801TSPAMVAC.000 [DIRS 185080].
Figure 7.7.1-56[a]. Failure Fraction for the Drip Shield Plate and Framework and the Fraction of the Collapsed Drift Filled with Rubble (Lithophysal Zone) for Realization 4641 of the Seismic Ground Motion Modeling Case for 1,000,000 Years after Repository Closure
Figure 7.7.1-57[a]. CDSP WP Failure for Each Percolation Subregion for Both Seeping and Non-Seeping Environments for Realization 4641 of the Seismic Ground Motion Modeling Case for 1,000,000 Years after Repository Closure
Figure 7.7.1-58[a]. CSNF WP Failure for Each Percolation Subregion for Both Seeping and Non-Seeping Environments for Realization 4641 of the Seismic Ground Motion Modeling Case for 1,000,000 Years after Repository Closure.
Figure 7.7.1-59[a]. CDSP WP Opening Area after Failure from Cracks and Patches for Percolation Subregion 3 for Realization 4641 of the Seismic Ground Motion Modeling Case for 1,000,000 Years after Repository Closure

Source: Output DTN: MO0801TSPAMVAC.000 [DIRS 185080].
Total System Performance Assessment Model/Analysis for the License Application

Figure 7.7.1-60[a]. CSNF WP Opening Area after Failure from Cracks and Patches for Percolation Subregion 3 for Realization 4641 of the Seismic Ground Motion Modeling Case for 1,000,000 Years after Repository Closure
Figure 7.7.1-61[a]. Average Waste Package Outer Barrier Thicknesses and Waste Package Failure Fractions for Percolation Subregion 3 for Realization 4641 of the Seismic Ground Motion Modeling Case for 1,000,000 Years after Repository Closure
Diffusive Release Rates of: (a) $^{99}$Tc and (b) $^{242}$Pu (Dissolved and Reversibly Associated with Colloids) from CDSP WPs from each Percolation Subregion for Realization 4641 of the Seismic Ground Motion Modeling Case for 1,000,000 Years after Repository Closure

Source: Output DTN: MO0801TSPAMVAC.000 [DIRS 185080].

Figure 7.7.1-62[a]. Diffusive Release Rates of: (a) $^{99}$Tc and (b) $^{242}$Pu (Dissolved and Reversibly Associated with Colloids) from CDSP WPs from each Percolation Subregion for Realization 4641 of the Seismic Ground Motion Modeling Case for 1,000,000 Years after Repository Closure.
Figure 7.7.1-63[a]. Dissolved Concentration of $^{242}$Pu in the Corrosion Products Domain Compared to the Sorbed Concentration on Corrosion Products for CDSP WPs for Percolation Subregion 3 Seeping Environment for Realization 4641 of the Seismic Ground Motion Modeling Case for 1,000,000 Years after Repository Closure.
Figure 7.7.1-64[a]. Diffusive Release Rates of (a) $^{99}$Tc and (b) $^{242}$Pu (Dissolved and Reversibly Associated with Colloids) from CSNF WPs from each Percolation Subregion for Realization 4641 of the Seismic Ground Motion Modeling Case for 1,000,000 Years after Repository Closure.

Source: Output DTN: MO0801TSPAMVAC.000 [DIRS 185080].
Comparison of $^{242}$Pu Cumulative Mass Released from the Inventory, Mass Sorbed on Corrosion Products, and the Dissolved Concentration in the Corrosion Products Domain for CSNF WPs for Percolation Subregion 3 Seeping Environment for Realization 4641 of the Seismic Ground Motion Modeling Case for 1,000,000 Years after Repository Closure
Figure 7.7.1-66[a]. pH and Ionic Strength Profiles in the Corrosion Products Domain for CSNF WPs for Percolation Subregion 3, Seeping Environment for Realization 4641 of the Seismic Ground Motion Modeling Case for 1,000,000 Years after Repository Closure.
Concentration of $^{242}\text{Pu}$ in the CSNF and CDSP WPs (Corrosion Products Domain) for Percolation Subregion 3 Seeping Environment for Realization 4641 of the Seismic Ground Motion Modeling Case for 1,000,000 Years after Repository Closure

Source: Output DTN: MO0801TSPAMVAC.000 [DIRS 185080].
Concentration of Various Colloids in the CSNF and CDSP WPs (Corrosion Products Domain) for Percolation Subregion 3 Seeping Environment for Realization 4641 of the Seismic Ground Motion Modeling Case for 1,000,000 Years after Repository Closure.
Total System Performance Assessment Model/Analysis for the License Application

NOTE: Plutonium dissolved and reversibly associated with colloids is denoted as aqueous.

Figure 7.7.1-69[a]. EBS Release Rates from CSNF and CDSP WPs (All Percolation Subregions) for Realization 4641 of the Seismic Ground Motion Modeling Case for 1,000,000 Years after Repository Closure

Source: Output DTN: MO0801TSPAMVAC.000 [DIRS 185080].
NOTE: Plutonium dissolved and reversibly associated with colloids is denoted as aqueous.
Fraction of $^{242}$Pu Mass Going to Unsaturated Zone Fractures at the Repository Horizon for Realization 4641 of the Seismic Ground Motion Modeling Case for 1,000,000 Years after Repository Closure

Source: Output DTN: MO0801TSPAMVAC.000 [DIRS 185080].

Figure 7.7.1-70[a]. Fraction of $^{242}$Pu Mass Going to Unsaturated Zone Fractures at the Repository Horizon for Realization 4641 of the Seismic Ground Motion Modeling Case for 1,000,000 Years after Repository Closure
NOTE: Plutonium dissolved and reversibly associated with colloids is denoted as aqueous.

Figure 7.7.1-71[a]. Cumulative Mass Release of $^{99}\text{Tc}$ and $^{242}\text{Pu}$ from the EBS, Unsaturated Zone, and Saturated Zone for Realization 4641 of the Seismic Ground Motion Modeling Case for 1,000,000 Years after Repository Closure
NOTES: The SZ breakthrough curve #122 is used in realization 4641. Plutonium dissolved and reversibly associated with colloids are denoted as aqueous.

Figure 7.7.1-72[a]. Comparison of Saturated Zone Breakthrough Curves for $^{99}$Tc and $^{242}$Pu for All Four Saturated Zone Source Regions for Realization 4641 of the Seismic Ground Motion Modeling Case for 1,000,000 Years after Repository Closure
Plutonium dissolved and reversibly associated with colloids is denoted as aqueous.

Figure 7.7.1-73[a]. Saturated Zone Release at the Location of the RMEI of $^{99}$Tc and $^{242}$Pu for Realization 4641 of the Seismic Ground Motion Modeling Case for 1,000,000 Years after Repository Closure
Figure 7.7.1-74[a]. Expected Annual Dose from 300 Epistemic Uncertainty Vectors, Along with their Quantiles for the Nominal Modeling Case for 1,000,000 Years after Repository Closure in (a) Linear Time and (b) Log Time
Figure 7.7.1-75[a]. Contribution of Individual Radionuclides to Mean Annual Dose for the Nominal Modeling Case for 1,000,000 Years after Repository Closure

Source: Output DTN: MO0710ADTSPAWO.000 [DIRS 183752].
Figure 7.7.1-76[a]. Expected Annual Dose from 300 Epistemic Uncertainty Vectors, Along with their Quantiles and Expected Dose from Epistemic Uncertainty Vector 286 for the Nominal Modeling Case for 1,000,000 Years after Repository Closure
Figure 7.7.1-77[a]. Contribution of Individual Radionuclides to Expected Annual Dose for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure

Source: Output DTN: MO0801TSPAMVAC.000 [DIRS 185080].
Figure 7.7.1-78[a]. Expected Number of (a) CDSP WP Failures and (b) CSNF WP Failures by Percolation Subregion for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure

Source: Output DTN: MO0801TSPAMVAC.000 [DIRS 185080].
Figure 7.7.1-79[a]. Average Failure Area for (a) CDSP WPs and (b) CSNF WPs by Percolation Subregion for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure

Source: Output DTN: MO0801TSPAMVC.000 [DIRS 185080].
Figure 7.7.1-80[a]. Release Rates of $^{129}$I from the Waste Form, Waste Package, Invert, Unsaturated Zone, and Saturated Zone for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure
Release Rates of $^{79}\text{Se}$ from the Waste Form, Waste Package, Invert, Unsaturated Zone, and Saturated Zone for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure.

Source: Output DTN: MO0801TSPAMVAC.000 [DIRS 185080].

Figure 7.7.1-81[a]. Release Rates of $^{79}\text{Se}$ from the Waste Form, Waste Package, Invert, Unsaturated Zone, and Saturated Zone for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure.
Figure 7.7.1-82[a]. Release Rates of $^{135}$Cs from the Waste Form, Waste Package, Invert, Unsaturated Zone, and Saturated Zone for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure

Source: Output DTN: MO0801TSPAMVAC.000 [DIRS 185080].
Figure 7.7.1-83[a]. Release Rates of $^{242}$Pu (Dissolved and Reversibly Associated with Colloids) from the Waste Form, Waste Package, Invert, Unsaturated Zone, and Saturated Zone for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure
Figure 7.7.1-84[a]. Diffusive and Advective Release Rates of $^{129}$I from the CDSP and CSNF Waste Packages for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure
Figure 7.7.1-85[a]. Diffusive and Advective Release Rates of $^{242}$Pu (Dissolved and Reversibly Associated with Colloids) from the CDSP and CSNF Waste Packages for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure
Figure 7.7.1-86[a]. Fraction of $^{129}$I Mass Going to Unsaturated Zone Fractures at the Repository Horizon for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure
Figure 7.7.1-87[a]. Fraction of $^{242}$Pu Mass Going to Unsaturated Zone Fractures at the Repository Horizon for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure

Source: Output DTN: MO0801TSPAMVAC.000 [DIRS 185080].
NOTE: Plutonium dissolved and reversibly associated with colloids is denoted as aqueous.

Figure 7.7.1-88[a]. Expected Annual Dose for Aqueous $^{242}$Pu and Slow and Fast Fractions of Irreversibly Sorbed Colloidal $^{242}$Pu for Realization 286 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure.
Figure 7.7.1-89[a]. Expected Annual Dose from the 300 Epistemic Uncertainty Vectors along with their Quantiles and Expected Dose from Epistemic Uncertainty Vector 85 for the Nominal Modeling Case for 1,000,000 Years after Repository Closure
Figure 7.7.1-90[a]. Contribution of Individual Radionuclides to Expected Annual Dose of Realization 85 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure

Source: Output DTN: MO0801TSPAMVAC.000 [DIRS 185080].
(a) Release Rates of $^{242}$Pu (Dissolved and Reversibly Associated with Colloids) from the Waste Form, Waste Package, Invert, Unsaturated Zone, and Saturated Zone,

(b) CSNF WP Failure History for Realization 85 of the Nominal Modeling Case for 1,000,000 Years after Repository Closure

Source: Output DTN: MO0801TSPAMVAC.000 [DIRS 185080].
Figure 7.7.1-92[a]. Expected Annual Dose from the 300 Epistemic Uncertainty Vectors along with their Quantiles and Expected Dose from Epistemic Uncertainty Vector 277 for the Human Intrusion Modeling Case for 1,000,000 Years after Repository Closure
Source: Output DTN: MO0710ADTSPAWO.000 [DIRS 183752].

NOTE: The dashed line is the annual dose from aleatory vector 29, which is equivalent to GoldSim realization 8309.

Figure 7.7.1-93[a]. Annual Dose from the Thirty Aleatory Vectors Associated with the Epistemic Uncertainty Vector 277 for the Human Intrusion Modeling Case for 1,000,000 Years after Repository Closure
Figure 7.7.1-94[a]. Annual Dose along with Major Radionuclide Dose Contributors for Realization 8309 of the Human Intrusion Modeling Case for 1,000,000 Years after Repository Closure
Figure 7.7.1-95[a]. Cumulative Release of $^{99}$Tc and $^{242}$Pu from the Inventory for Percolation Subregion 4 for Realization 8309 of the Human Intrusion Modeling Case for 1,000,000 Years after Repository Closure.
Advecive and Diffusive Release Rates of $^{99}$Tc from Waste Form and Corrosion Products Domain for failed CSNF WPs for Realization 8309 of the Human Intrusion Modeling Case for 1,000,000 Years after Repository Closure
NOTE: Plutonium dissolved and reversibly associated with colloids is denoted as aqueous.

Figure 7.7.1-97[a]. Adveotive and Diffusive Release Rates of $^{242}\text{Pu}$ (Aqueous) from Waste Form and Corrosion Products Domain and $^{242}\text{Pu}$ (Irreversibly Sorbed on Iron Oxyhydroxide Colloids) from Corrosion Products Domain for failed CSNF WPs for Realization 8309 of the Human Intrusion Modeling Case for 1,000,000 years after Repository Closure.
Dissolved Concentration of $^{242}$Pu in the Waste Form and Corrosion Products Domain, the Plutonium Solubility in Respective Domains, and Concentration of $^{242}$Pu Irreversibly Sorbed on Iron Oxyhydroxide Colloids for Realization 8309 of the Human Intrusion Modeling Case for 1,000,000 Years after Repository Closure
Figure 7.7.1-99[a]. Comparison of $^{99}$Tc Release from Waste Package, Unsaturated Zone Borehole, and Saturated Zone for Realization 8309 of the Human Intrusion Modeling Case for 1,000,000 Years after Repository Closure.
Figure 7.7.1-100[a]. Comparison of $^{242}\text{Pu}$ (Dissolved and Reversibly Associated with Colloids) Release from Waste Package, Unsaturated Zone Borehole, and Saturated Zone for Realization 8309 of the Human Intrusion Modeling Case for 1,000,000 Years after Repository Closure
NOTE: Plutonium dissolved and reversibly associated with colloids is denoted as aqueous.

Figure 7.7.1-101[a]. Cumulative Release Comparison of $^{99}$Tc, $^{242}$Pu (Aqueous), and $^{242}$Pu (Irreversibly Sorbed on Colloids) from Waste Package, Unsaturated Zone Borehole, and Saturated Zone for Realization 8309 of the Human Intrusion Modeling Case for 1,000,000 Years after Repository Closure
NOTE: Plutonium dissolved and reversibly associated with colloids is denoted as aqueous.

Figure 7.7.1-102[a]. Saturated Zone Release Rates to the Biosphere for $^{99}$Tc, $^{242}$Pu (Aqueous), $^{242}$Pu (Irreversibly Sorbed on Colloids that Travel Slowly due to Retardation), and $^{242}$Pu (Irreversibly Sorbed on Colloids that Travel Fast due to no Retardation) for Realization 8309 of the Human Intrusion Modeling Case for 1,000,000 Years after Repository Closure
Figure 7.7.1-103[a]. Expected Annual Dose from the 300 Epistemic Uncertainty Vectors along with their Quantiles and Expected Dose from Epistemic Uncertainty Vector 181 for the Human Intrusion Modeling Case for 1,000,000 Years after Repository Closure
Source: Output DTN: MO0710ADTSPAWO.000 [DIRS 183752].

Figure 7.7.1-104[a]. Annual Dose from the Thirty Aleatory Vectors Associated with the Epistemic Uncertainty Vector 181 for the Human Intrusion Modeling Case for 1,000,000 Years after Repository Closure
Figure 7.7.1-105[a]. Annual Dose along with Major Radionuclide Dose Contributors for Realization 5415 of the Human Intrusion Modeling Case for 1,000,000 Years after Repository Closure.
Figure 7.7.1-106[a]. Dissolved Concentration of $^{242}$Pu in the Waste Form and Corrosion Products Domains, the Plutonium Solubility in Respective Domains, and Concentration of $^{242}$Pu Irreversibly Sorbed on Iron Oxyhydroxide Colloids for Realization 5415 of the Human Intrusion Modeling Case for 1,000,000 Years after Repository Closure.

Source: Output DTN: MO0801TSPAMVC.000 [DIRS 185080].
Figure 7.7.1-107[a]. Expected Annual Dose from the 300 Epistemic Uncertainty Vectors along with their Quantiles and Expected Dose from Epistemic Uncertainty Vector 155 for the Seismic Ground Motion Modeling Case for 10,000 Years after Repository Closure
Figure 7.7.1-108[a]. Annual Dose from the Thirty Aleatory Vectors Associated with the Epistemic Uncertainty Vector 155 for the Seismic Ground Motion Modeling Case for 10,000 Years after Repository Closure
Figure 7.7.1-109[a]. Annual Dose along with Major Radionuclide Dose Contributors for Realization 4628 of the Seismic Ground Motion Modeling Case for 10,000 Years after Repository Closure

Source: Output DTN: MO0801TSPAMVAC.000 [DIRS 185080].
Figure 7.7.1-110[a]. CDSP WP Failure History in all Five Percolation Subregions for Both Seeping and Non-Seeping Environments for Realization 4628 of the Seismic Ground Motion Modeling Case for 10,000 Years after Repository Closure

Source: Output DTN: MO0801TSPAMVAC.000 [DIRS 185080].
Figure 7.7.1-111[a]. Diffusive Release Rates of $^{99}$Tc from CDSP WPs from each Percolation Subregion for Realization 4628 of the Seismic Ground Motion Modeling Case for 10,000 Years after Repository Closure

Source: Output DTN: MO0801TSPAMVAC.000 [DIRS 185080].
Figure 7.7.1-112[a]. Diffusive Release Rates of $^{79}\text{Se}$ from CDSP WPs from each Percolation Subregion for Realization 4628 of the Seismic Ground Motion Modeling Case for 10,000 Years after Repository Closure.
Source: Output DTN: MO0801TSPAMVAC.000 [DIRS 185080].

Figure 7.7.1-113[a]. Mass Flux of $^{99}$Tc from the EBS for Percolation Subregion 3 (Seeping and Non-Seeping Environments) for Realization 4628 of the Seismic Ground Motion Modeling Case for 10,000 Years after Repository Closure
Figure 7.7.1-114[a]. Comparison of Dissolved Concentration of $^{99}$Tc from the Various EBS Transport Domains and Fraction of HLW Degraded for CDSP Percolation Subregion 3, Non-Seeping Environment for Realization 4628 of the Seismic Ground Motion Modeling Case for 10,000 Years after Repository Closure
Figure 7.7.1-115[a]. Comparison of Diffusive Releases of $^{99}$Tc from the Various EBS Transport Domains for CDSP Percolation Subregion 3 Non-Seeping Environment for Realization 4628 of the Seismic Ground Motion Modeling Case for 10,000 Years after Repository Closure.

Source: Output DTN: MO0801TSPAMVC.000 [DIRS 185080].
Figure 7.7.1-116[a]. Fraction of $^{99}$Tc Mass Going to Unsaturated Zone Fractures as Compared to the Unsaturated Zone Matrix at the Repository Horizon for Realization 4628 of the Seismic Ground Motion Modeling Case for 10,000 Years after Repository Closure.
Figure 7.7.1-117[a]. Fraction of $^{79}$Se Mass Going to Unsaturated Zone Fractures as Compared to the Unsaturated Zone Matrix at the Repository Horizon for Realization 4628 of the Seismic Ground Motion Modeling Case for 10,000 Years after Repository Closure

Source: Output DTN: MO0801TSPAMVAC.000 [DIRS 185080].
Figure 7.7.1-118[a]. Cumulative Release of $^{99}$Tc from Various Model Domains for Realization 4628 of the Seismic Ground Motion Modeling Case for 10,000 Years after Repository Closure

Source: Output DTN: MO0801TSPAMVAC.000 [DIRS 185080].
Figure 7.7.1-119[a]. Cumulative Release of $^{79}\text{Se}$ from Various Model Domains for Realization 4628 of the Seismic Ground Motion Modeling Case for 10,000 Years after Repository Closure

Source: Output DTN: MO0801TSPAMVC.000 [DIRS 185080].
NOTES: The SZ Breakthrough Curve #122 is used in realization 4628.

Figure 7.7.1-120[a]. Comparison of Saturated Zone Breakthrough Curves for $^{99}$Tc and $^{79}$Se for All Four Saturated Zone Regions for Realization 4628 of the Seismic Ground Motion Modeling Case for 10,000 Years after Repository Closure
Figure 7.7.1-121[a]. Saturated Zone Release to the Biosphere for $^{99}$Tc and $^{79}$Se for Realization 4628 of the Seismic Ground Motion Modeling Case for 10,000 Years after Repository Closure
Figure 7.7.2-3[a]. Time-Slice Comparison of the Simplified TSPA Analysis Results against the TSPA-LA Model Results for the Waste Package Early Failure Modeling Case
Figure 7.7.2-6[a]. Time-Slice Comparison of the Simplified TSPA Analysis Results against the TSPA-LA Model Results for the Nominal Modeling Case

Source: Output DTN: MO0710ADTSPAWO.000 [DIRS 183752]; and Corroborative DTN: MO0708SIMPLIFI.000 [DIRS 182980].
Total System Performance Assessment Model/Analysis for the License Application

Source: Output DTN: MO0710ADTSPAWO.000 [DIRS 183752]; and Corroborative DTN: MO0708SIMPLIFI.000 [DIRS 182980].

Figure 7.7.2-9[a]. Time-Slice Comparison of the Simplified TSPA Analysis Results against the TSPA-LA Model Results for the Seismic Ground Motion Modeling Case
Figure 7.7.2-12[a]. Time-Slice Comparison of the Simplified TSPA Analysis Results against the TSPA-LA Model Results for the Igneous Intrusion Modeling Case

Source: Output DTN: MO0710ADTSPAWO.000 [DIRS 183752]; and Corroborative DTN: MO0708SIMPLIFI.000 [DIRS 182980].
Figure 7.7.3-2[a]. TSPA-LA Nominal Scenario Class Mean Failure Curves for the Drip Shield and Waste Package

Source: Output DTN: MO0710ADTSPAWO.000 [DIRS 183752].
Figure 7.7.3-3[a]. TSPA-LA Mean Annual Dose for Major Radionuclides for the Combined Early Failure and Nominal Scenario Classes

Source: Output DTN: MO0710ADTSPAWO.000 [DIRS 183752].
Figure 7.7.4-7[a]. Comparison of Total Mean Annual Dose for TSPA-LA Model Version 5.000, Version 5.005, and the Performance Margin Analysis for: (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure
Total System Performance Assessment
Model/Analysis for the License Application
Addendum 01

Volume III
DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, nor any of their contractors, subcontractors or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or any third party’s use or the results of such use of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof or its contractors or subcontractors. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.
## CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>8[a]</td>
<td>POSTCLOSURE PERFORMANCE DEMONSTRATION</td>
<td>8-1[a]</td>
</tr>
<tr>
<td>8.1[a]</td>
<td>CONFORMANCE WITH RADIATION PROTECTION STANDARDS</td>
<td>8-2[a]</td>
</tr>
<tr>
<td>8.1.1[a]</td>
<td>Individual Protection Standard</td>
<td>8-3[a]</td>
</tr>
<tr>
<td>8.1.2[a]</td>
<td>Groundwater Protection</td>
<td>8-14[a]</td>
</tr>
<tr>
<td>8.1.3[a]</td>
<td>Human Intrusion Protection</td>
<td>8-21[a]</td>
</tr>
<tr>
<td>8.2[a]</td>
<td>PROJECTIONS FOR INDIVIDUAL MODELING CASES</td>
<td>8-27[a]</td>
</tr>
<tr>
<td>8.2.1[a]</td>
<td>Nominal Modeling Case</td>
<td>8-27[a]</td>
</tr>
<tr>
<td>8.2.2[a]</td>
<td>Early Failure Scenario Class Modeling Cases</td>
<td>8-29[a]</td>
</tr>
<tr>
<td>8.2.3[a]</td>
<td>Igneous Scenario Class Modeling Cases</td>
<td>8-32[a]</td>
</tr>
<tr>
<td>8.2.4[a]</td>
<td>Seismic Scenario Class Modeling Cases</td>
<td>8-34[a]</td>
</tr>
<tr>
<td>8.3[a]</td>
<td>DESCRIPTION OF MULTIPLE BARRIER CAPABILITY</td>
<td>8-39[a]</td>
</tr>
<tr>
<td>8.3.1[a]</td>
<td>Radionuclides Selected to Demonstrate Multiple Barrier Capability</td>
<td>8-39[a]</td>
</tr>
<tr>
<td>8.3.2[a]</td>
<td>Identification of Barriers for Yucca Mountain Repository</td>
<td>8-39[a]</td>
</tr>
<tr>
<td>8.3.3[a]</td>
<td>Demonstration of Multiple Barrier Capability</td>
<td>8-40[a]</td>
</tr>
<tr>
<td>8.4[a]</td>
<td>VALIDITY AND DEFENSIBILITY OF PERFORMANCE DEMONSTRATION</td>
<td>8-85[a]</td>
</tr>
<tr>
<td>8.4.1[a]</td>
<td>Validation of TSPA Model and Component Models</td>
<td>8-85[a]</td>
</tr>
<tr>
<td>8.4.2[a]</td>
<td>Verification and Validation of TSPA Software and Input Data</td>
<td>8-85[a]</td>
</tr>
<tr>
<td>8.4.3[a]</td>
<td>Uncertainty Characterization Reviews</td>
<td>8-85[a]</td>
</tr>
<tr>
<td>8.4.4[a]</td>
<td>Corroboration of TSPA-LA Results</td>
<td>8-85[a]</td>
</tr>
<tr>
<td>8.4.5[a]</td>
<td>Peer Reviews of YMP TSPA Methodology</td>
<td>8-85[a]</td>
</tr>
<tr>
<td>9[a]</td>
<td>INPUTS AND REFERENCES</td>
<td>9-1[a]</td>
</tr>
<tr>
<td>9.1[a]</td>
<td>DOCUMENTS CITED</td>
<td>9-1[a]</td>
</tr>
<tr>
<td>9.2[a]</td>
<td>CODES, STANDARDS, REGULATIONS, AND PROCEDURES</td>
<td>9-9[a]</td>
</tr>
<tr>
<td>9.3[a]</td>
<td>SOFTWARE CODES</td>
<td>9-9[a]</td>
</tr>
<tr>
<td>9.4[a]</td>
<td>SOURCE DATA LISTED BY DATA TRACKING NUMBER</td>
<td>9-11[a]</td>
</tr>
</tbody>
</table>

APPENDIX B[a] DATA TRACKING NUMBERS FOR THE TSPA-LA MODEL | B-1[a] |
APPENDIX C[a] PERFORMANCE MARGIN ANALYSIS | C-1[a] |
APPENDIX D[a] PARAMETER LISTING | D-1[a] |
APPENDIX H[a] YUCCA MOUNTAIN REVIEW PLAN ACCEPTANCE CRITERIA | H-1[a] |
APPENDIX I[a] FEATURES, EVENTS, AND PROCESSES MAPPED TO TSPA-LA MODEL | I-1[a] |
APPENDIX J[a] CONCEPTUAL STRUCTURE OF TSPA-LA | J-1[a] |
APPENDIX K[a] UNCERTAINTY AND SENSITIVITY ANALYSIS RESULTS | K-1[a] |
APPENDIX M[a] COMPARISON WITH ELECTRIC POWER RESEARCH INSTITUTE ANALYSIS | M-1[a] |
APPENDIX P[a] IMPACT ASSESSMENTS | P-1[a] |
### FIGURES

<table>
<thead>
<tr>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.1-1[a]. Distribution of Total Expected Annual Dose for 10,000 Years after Repository Closure</td>
</tr>
<tr>
<td>8.1-2[a]. Distribution of Total Expected Annual Dose for 1,000,000 Years after Closure</td>
</tr>
<tr>
<td>8.1-3[a]. Relative Contributions of Modeling Cases to Total Mean Annual Dose for (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure</td>
</tr>
<tr>
<td>8.1-4[a]. Histogram of the Time of Drip Shield Failure for the Nominal and Seismic Ground Motion Modeling Cases</td>
</tr>
<tr>
<td>8.1-5[a]. Fraction of (a) CDSP Waste Packages and (b) CSNF Waste Packages Failed by Seismic Damage as a Function of Time</td>
</tr>
<tr>
<td>8.1-6[a]. Contribution of Individual Radionuclides to Total Mean Annual Dose for 10,000 Years after Repository Closure</td>
</tr>
<tr>
<td>8.1-7[a]. Contribution of Individual Radionuclides to Total Mean Annual Dose for 1,000,000 Years after Repository Closure</td>
</tr>
<tr>
<td>8.1-9[a]. Summary Statistics for Activity Concentrations of Total Radium (Ra and Ra) in Groundwater, Excluding Natural Background, for 10,000 Years after Repository Closure</td>
</tr>
<tr>
<td>8.1-10[a]. Contributions of the Modeling Cases to the Mean Combined Ra and Ra Activity Concentration in Groundwater, Excluding Natural Background, for 10,000 Years after Repository Closure</td>
</tr>
<tr>
<td>8.1-11[a]. Summary Statistics for Activity Concentration of Gross Alpha and Ra (Excluding Radon and Uranium) in Groundwater for 10,000 Years after Repository Closure</td>
</tr>
<tr>
<td>8.1-12[a]. Contributions of the Modeling Cases to the Mean Gross Alpha Activity Concentrations (Including Ra but Excluding Radon and Uranium) in Groundwater for 10,000 Years after Repository Closure</td>
</tr>
<tr>
<td>8.1-13[a]. Mean Annual Dose from Beta-Photon Dose for All Organs, Including the Whole Body for (a) 10,000 Years after Repository Closure and (b) Detail for 8,000 to 10,000 Years after Repository Closure</td>
</tr>
<tr>
<td>8.1-14[a]. Summary Statistics for Annual Drinking Water Doses for Combined Beta and Photon Emitting Radionuclides for 10,000 Years after Repository Closure</td>
</tr>
<tr>
<td>8.1-15[a]. Contributions of Modeling Cases to the (a) Whole Body Dose and (b) Thyroid for 10,000 Years after Repository Closure</td>
</tr>
<tr>
<td>8.1-16[a]. Distribution of Expected Annual Doses for the Human Intrusion Scenario for 1,000,000 Years after Repository Closure with Drilling Event at 200,000 Years</td>
</tr>
<tr>
<td>8.1-17[a]. Contribution of Individual Radionuclides to Mean Annual Dose for the Human Intrusion Scenario for 1,000,000 Years after Repository Closure</td>
</tr>
</tbody>
</table>
FIGURES (Continued)

8.2-1[a]. Distributions of Expected Annual Dose for the Nominal Modeling Case for 1,000,000 Years after Repository Closure ..............................................F8.2-1[a]

8.2-2[a]. Contribution of Individual Radionuclides to Mean Annual Dose for the Nominal Modeling Case for 1,000,000 Years after Repository Closure .........................................................F8.2-2[a]

8.2-3[a]. Distributions of Expected Annual Dose for the Drip Shield Early Failure Modeling Case for (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure .........................................................F8.2-3[a]

8.2-4[a]. Contribution of Individual Radionuclides to Mean Annual Dose for Drip Shield Early Failure Modeling Case for (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure .........................................................F8.2-4[a]

8.2-5[a]. Distributions of Expected Annual Dose for Waste Package Early Failure Modeling Case for (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure .........................................................F8.2-5[a]

8.2-6[a]. Contribution of Individual Radionuclides to Mean Annual Dose for Waste Package Early Failure Modeling Case for (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure .........................................................F8.2-6[a]

8.2-7[a]. Distributions of Expected Annual Dose for the Igneous Intrusion Modeling Case for (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure .........................................................F8.2-7[a]

8.2-8[a]. Contribution of Individual Radionuclides to Mean Annual Dose for the Igneous Intrusion Modeling Case for (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure .........................................................F8.2-8[a]

8.2-9[a]. Distributions of Expected Annual Dose for the Seismic Ground Motion Modeling Case for (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure .........................................................F8.2-9[a]

8.2-10[a]. Contribution of Individual Radionuclides to Mean Annual Dose for the Seismic Ground Motion Modeling Case for (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure .........................................................F8.2-10[a]

8.2-11[a]. Distributions of Expected Annual Dose for the Seismic Fault Displacement Modeling Case for (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure .........................................................F8.2-11[a]

8.2-12[a]. Contribution of Individual Radionuclides to Mean Annual Dose for the Seismic Fault Displacement Modeling Case for (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure .........................................................F8.2-12[a]

8.3-1[a]. Mean Radionuclide Activities for Total Repository Inventory as a Function of Time for (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure .........................................................F8.3-1[a]

8.3-2[a]. Mean Radionuclide Contributions to Total Inventory as a Function of Time for (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure .........................................................F8.3-2[a]

8.3-3[a]. Upper Natural Barrier Capability to Prevent or Substantially Reduce the Rate of Water Movement to the Waste for the Mean
FIGURES (Continued)

Spatially-Averaged (a) Annual Precipitation, Net Infiltration, and Post-10,000-Year Percolation Rates and (b) Drift Seepage Fluxes for the Combined Nominal/Early Failure Modeling Case and the Seismic Ground Motion Modeling Case – 1,000,000-Year Period.............F8.3-3[a]

8.3-4[a]. Probability of Drip Shield Failure by General Corrosion for the Nominal Modeling Case Based on 300 Epistemic Realizations of Drip Shield General Corrosion Rates ...............................................................F8.3-3[a]

8.3-5[a]. Summary Statistics for Fraction of Waste Packages Breached for (a) CSNF Waste Packages and (b) CDSP Waste Packages for the Nominal Modeling Case as a Function of Time ............................................F8.3-5[a]

8.3-6[a]. Summary Statistics for Fraction of CSNF Waste Packages (a) reached by Stress Corrosion Cracking and (b) Breached by General Corrosion Patches for the Nominal Modeling Case as a Function of Time.................................................................F8.3-6[a]

8.3-7[a]. Cumulative Distribution Functions of Drip Shield Failure Time for (a) Distributions of Failure Time for 300 Epistemic Sample Elements and (b) Distribution of Expected (Over Aleatory) Failure Time with Confidence Interval for the Seismic Ground Motion Modeling Case ....F8.3-7[a]

8.3-8[a]. Summary Statistics for Expected Fraction of CSNF WPs (a) Breached by Seismic and Nominal Processes and (b) Breached by Seismic Processes Only; and CDSP WPs (c) Breached by Seismic and Nominal Processes and (d) Breached by Seismic Processes Only for the Seismic Ground Motion Modeling Case as a Function of Time ........................................................................F8.3-8[a]

8.3-9[a]. Summary Statistics for Average Fraction of CSNF Waste Package Surface Breached by Cracks per Breached Waste Package for (a) the Seismic Ground Motion Modeling Case and (b) the Nominal Modeling Case as a Function of Time .................................................................F8.3-9[a]

8.3-10[a]. Summary Statistics for Fraction of CDSP Waste Package Surface Breached by Cracks per Breached Waste Package for (a) the Seismic Ground Motion Modeling Case and (b) the Nominal Modeling Case as a Function of Time .................................................................F8.3-10[a]

8.3-11[a]. Summary Statistics for Fraction of CSNF Waste Package Surface Breached by Patches per Breached Waste Package for (a) the Seismic Ground Motion Modeling Case and (b) the Nominal Modeling Case as a Function of Time .................................................................F8.3-11[a]

8.3-12[a]. Summary Statistics for Fraction of CDSP WP Surface Breached by Patches per Breached Waste Package for (a) the Seismic Ground Motion Modeling Case and (b) the Nominal Modeling Case as a Function of Time .................................................................F8.3-12[a]

8.3-13[a]. Mean Activity Released from the Engineered Barrier System for the Combined Nominal/Early Failure Modeling Case for (a) 10,000 Years after Repository Closure and (b) Post-10,000-Years after Repository Closure.................................................................F8.3-13[a]

8.3-14[a].
<table>
<thead>
<tr>
<th>FIGURES (Continued)</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.3-14[a]. Uncertainty in Activity of $^{99}$Tc Released from the Engineered Barrier System for the Combined Nominal/Early Failure Modeling Case for (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure</td>
<td>F8.3-15[a]</td>
</tr>
<tr>
<td>8.3-15[a]. Uncertainty in Activity of $^{239}$Pu Released from the Engineered Barrier System for the Combined Nominal/Early Failure Modeling Case for (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure</td>
<td>F8.3-16[a]</td>
</tr>
<tr>
<td>8.3-16[a]. Mean Activity Released from the Engineered Barrier System for the Seismic Ground Motion Modeling Case for (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure</td>
<td>F8.3-17[a]</td>
</tr>
<tr>
<td>8.3-17[a]. Uncertainty in Activity of $^{99}$Tc Released from the Engineered Barrier System for the Seismic Ground Motion Modeling Case for (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure</td>
<td>F8.3-18[a]</td>
</tr>
<tr>
<td>8.3-18[a]. Uncertainty in Activity of $^{237}$Np Released from the Engineered Barrier System for the Seismic Ground Motion Modeling Case for (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure</td>
<td>F8.3-19[a]</td>
</tr>
<tr>
<td>8.3-19[a]. Uncertainty in Activity of $^{234}$U Released from the Engineered Barrier System for the Seismic Ground Motion Modeling Case for (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure</td>
<td>F8.3-20[a]</td>
</tr>
<tr>
<td>8.3-20[a]. Uncertainty in Activity of $^{226}$Ra Released from the Engineered Barrier System for the Seismic Ground Motion Modeling Case for (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure</td>
<td>F8.3-21[a]</td>
</tr>
<tr>
<td>8.3-21[a]. Uncertainty in Activity of $^{239}$Pu Released from the Engineered Barrier System for the Seismic Ground Motion Modeling Case for (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure</td>
<td>F8.3-22[a]</td>
</tr>
<tr>
<td>8.3-22[a]. Uncertainty in Activity of $^{242}$Pu Released from the Engineered Barrier System for the Seismic Ground Motion Modeling Case for (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure</td>
<td>F8.3-23[a]</td>
</tr>
<tr>
<td>8.3-23[a]. Mean Activity Released from the (a) Saturated Zone and (b) Engineered Barrier System for the Combined Nominal/Early Failure Modeling Case for 10,000 Years after Repository Closure</td>
<td>F8.3-24[a]</td>
</tr>
<tr>
<td>8.3-24[a]. Mean Activity Released from the (a) Saturated Zone and (b) Engineered Barrier System for the Combined Nominal/Early Failure Modeling Case for 1,000,000 Years after Repository Closure</td>
<td>F8.3-25[a]</td>
</tr>
<tr>
<td>8.3-25[a]. Mean Activity Released from the (a) Saturated Zone and (b) Engineered Barrier System for the Seismic Ground Motion Modeling Case for 10,000 Years after Repository Closure</td>
<td>F8.3-26[a]</td>
</tr>
<tr>
<td>8.3-26[a]. Mean Activity Released from the (a) Saturated Zone and (b) Engineered Barrier System for the Seismic Ground Motion Modeling Case for 1,000,000 Years after Repository Closure</td>
<td>F8.3-27[a]</td>
</tr>
<tr>
<td>8.3-27[a]. Uncertainty in Activity of $^{99}$Tc Released from the Saturated Zone for the Seismic Ground Motion Modeling Case for (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure</td>
<td>F8.3-28[a]</td>
</tr>
</tbody>
</table>
FIGURES (Continued)

8.3-28[a]. Uncertainty in Activity of $^{237}$Np Released from the Saturated Zone for the Seismic Ground Motion Modeling Case for (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure ...........................................F8.3-29[a]

8.3-29[a]. Uncertainty in Activity of $^{234}$U Released from the Saturated Zone for the Seismic Ground Motion Modeling Case for (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure ...........................................F8.3-30[a]

8.3-30[a]. Uncertainty in Activity of $^{226}$Ra Released from the Saturated Zone for the Seismic Ground Motion Modeling Case for (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure ...........................................F8.3-31[a]

8.3-31[a]. Uncertainty in Activity of $^{239}$Pu Released from the Saturated Zone for the Seismic Ground Motion Modeling Case for (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure ...........................................F8.3-32[a]

8.3-32[a]. Uncertainty in Activity of $^{242}$Pu Released from the Saturated Zone for the Seismic Ground Motion Modeling Case for (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure ...........................................F8.3-33[a]

B-3[a]. Road Map of TSPA-LA Model v5.005 Data Tracking Numbers ..............B-5[a]

K4.5-1[a]. Dose to RMEI ($DOSTOT$, mrem/yr) for all radioactive species under nominal conditions obtained with version 5.005 of the TSPA-LA Model: (a) $DOSTOT$ for all (i.e., 300) sample elements, (b) $DOSTOT$ for first 50 sample elements, (c) PRCCs for $DOSTOT$ for [0; 1,000,000 yr], and (d) PRCCs for $DOSTOT$ for [200,000; 1,000,000 yr] .......................................................... FK-1[a]

K4.5-2[a]. Stepwise rank regression analyses and selected scatterplots for dose to RMEI ($DOSTOT$, mrem/yr) for all radioactive species under nominal conditions obtained with version 5.005 of the TSPA-LA Model: (a) regressions for $DOSTOT$ at 400,000, 600,000, and 800,000 years, and (b,c,d) scatterplots for $DOSTOT$ at 600,000 years ................................ FK-2[a]

K5.7.1-1[a]. Expected dose to RMEI ($EXPDOSE$, mrem/yr) over [0, 20,000 yr] for all radioactive species resulting from early DS failure obtained with version 5.005 of the TSPA-LA Model: (a) $EXPDOSE$ for all (i.e., 300) sample elements, (b) $EXPDOSE$ for first 50 sample elements, and (c) PRCCs for $EXPDOSE$ ............................................... FK-3[a]

K5.7.1-2[a]. Stepwise rank regression analyses and selected scatterplots for expected dose to RMEI ($EXPDOSE$, mrem/yr) over [0, 20,000 yr] for all radioactive species resulting from early DS failure obtained with version 5.005 of the TSPA-LA Model: (a) regressions for $EXPDOSE$ at 3,000, 5,000, and 10,000 years, and (b,c,d) scatterplots for $EXPDOSE$ at 10,000 years ................................................. FK-4[a]

K5.7.1-3[a]. Expected dose to RMEI ($EXPDOSE$, mrem/yr) over [0, 1,000,000 yr] for all radioactive species resulting from early DS failure obtained with version 5.005 of the TSPA-LA Model: (a) $EXPDOSE$ for all...
FIGURES (Continued)

(i.e., 300) sample elements, (b) EXPDOSE for first 50 sample elements, and (c) PRCCs for EXPDOSE

K5.7.1-4[a]. Stepwise rank regression analyses and selected scatterplots for expected dose to RMEI (EXPDOSE, mrem/yr) over [0, 1,000,000 yr] for all radioactive species resulting from early DS failure obtained with version 5.005 of the TSPA-LA Model: (a) regressions for EXPDOSE at 50,000, 200,000, and 500,000 years, and (b,c,d) scatterplots for EXPDOSE at 500,000 years

K5.7.2-1[a]. Expected dose to RMEI (EXPDOSE, mrem/yr) over [0, 20,000 yr] for all radioactive species resulting from early WP failure obtained with version 5.005 of the TSPA-LA Model: (a) EXPDOSE for all (i.e., 300) sample elements, (b) EXPDOSE for first 50 sample elements, and (c) PRCCs for EXPDOSE

K5.7.2-2[a]. Stepwise rank regression analyses and selected scatterplots for expected dose to RMEI (EXPDOSE, mrem/yr) over [0, 20,000 yr] for all radioactive species resulting from early WP failure obtained with version 5.005 of the TSPA-LA Model: (a) regressions for EXPDOSE at 3,000, 5,000, and 10,000 years, and (b,c,d) scatterplots for EXPDOSE at 10,000 years

K5.7.2-3[a]. Expected dose to RMEI (EXPDOSE, mrem/yr) over [0, 1,000,000 yr] for all radioactive species resulting from early WP failure obtained with version 5.005 of the TSPA-LA Model: (a) EXPDOSE for all (i.e., 300) sample elements, (b) EXPDOSE for first 50 sample elements, and (c) PRCCs for EXPDOSE

K5.7.2-4[a]. Stepwise rank regression analyses and selected scatterplots for expected dose to RMEI (EXPDOSE, mrem/yr) over [0, 1,000,000 yr] for all radioactive species resulting from early WP failure obtained with version 5.005 of the TSPA-LA Model: (a) regressions for EXPDOSE at 50,000, 200,000, and 500,000 years, and (b,c,d) scatterplots for EXPDOSE at 500,000 years

K6.3.2-5[a]. Time-dependent release rates (ESU234, g/yr) and cumulative (i.e., integrated) releases (ESU234C, g) over 1,000,000 years for the movement of dissolved $^{234}$U from the EBS to the UZ resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository obtained with version 5.005 of the TSPA-LA Model: (a,b) ESU234 and ESU234C for all (i.e., 300) sample elements, (c,d) ESU234 and ESU234C for first 50 sample elements, and (e,f) PRCCs for ESU234 and ESU234C

K6.3.2-6[a]. Stepwise rank regression analyses and selected scatterplots for time-dependent release rates (ESU234, g/yr) and cumulative (i.e., integrated) releases (ESU234C, g) for the movement of dissolved $^{234}$U from the EBS to the UZ resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository obtained with
version 5.005 of the TSPA-LA Model: (a,b) regressions for $ESU234$ and $ESU234C$ at 50,000, 200,000, and 500,000 years, and (c-h) scatterplots for $ESU234$ and $ESU234C$ at 500,000 years ................. FK-12[a]

K6.3.2-7[a]. Time-dependent release rates ($ESTH230$, $g$/yr) and cumulative (i.e., integrated) releases ($ESTH230C$, g) over 1,000,000 years for the movement of dissolved $^{230}$Th from the EBS to the UZ resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository obtained with version 5.005 of the TSPA-LA Model: (a,b) $ESTH230$ and $ESTH230C$ for all (i.e., 300) sample elements, (c,d) $ESTH230$ and $ESTH230C$ for first 50 sample elements, and (e,f) PRCCs for $ESTH230$ and $ESTH230C$................................................ FK-14[a]

K6.3.2-8[a]. Stepwise rank regression analyses and selected scatterplots for time-dependent release rates ($ESTH230$, $g$/yr) and cumulative (i.e., integrated) releases ($ESTH230C$, g) for the movement of dissolved $^{230}$Th from the EBS to the UZ resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository obtained with version 5.005 of the TSPA-LA Model: (a,b) regressions for $ESTH230$ and $ESTH230C$ at 50,000, 200,000, and 500,000 years, and (c-h) scatterplots for $ESTH230$ and $ESTH230C$ at 200,000 years ...... FK-15[a]

K6.3.2-9[a]. Time-dependent release rates ($ESRA226$, $g$/yr) and cumulative (i.e., integrated) releases ($ESRA226C$, g) over 1,000,000 years for the movement of dissolved $^{226}$Ra from the EBS to the UZ resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository obtained with version 5.005 of the TSPA-LA Model: (a,b) $ESRA226$ and $ESRA226C$ for all (i.e., 300) sample elements, (c,d) $ESRA226$ and $ESRA226C$ for first 50 sample elements, and (e,f) PRCCs for $ESRA226$ and $ESRA226C$ ................................................ FK-17[a]

K6.3.2-10[a]. Stepwise rank regression analyses and selected scatterplots for time-dependent release rates ($ESRA226$, $g$/yr) and cumulative (i.e., integrated) releases ($ESRA226C$, g) for the movement of dissolved $^{226}$Ra from the EBS to the UZ resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository obtained with version 5.005 of the TSPA-LA Model: (a,b) regressions for $ESRA226$ and $ESRA226C$ at 50,000, 200,000, and 500,000 years, and (c-h) scatterplots for $ESRA226$ and $ESRA226C$ at 50,000 years......... FK-18[a]

K6.4.2-1[a]. Time-dependent release rates ($UZU234$, $g$/yr) and cumulative (i.e., integrated) releases ($UZU234C$, g) over 1,000,000 years for the movement of dissolved $^{234}$U from the UZ to the SZ resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository obtained with version 5.005 of the TSPA-LA Model: (a,b) $UZU234$ and $UZU234C$ for all (i.e., 300) sample elements, (c,d) $UZU234$ and $UZU234C$ for first 50 sample elements, and (e,f) PRCCs for $UZU234$ and $UZU234C$............................................... FK-20[a]
### FIGURES (Continued)

<table>
<thead>
<tr>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>K6.4.2-2[a].</td>
</tr>
<tr>
<td>K6.4.2-3[a].</td>
</tr>
<tr>
<td>K6.4.2-4[a].</td>
</tr>
<tr>
<td>K6.4.2-5[a].</td>
</tr>
<tr>
<td>K6.4.2-6[a].</td>
</tr>
<tr>
<td>K6.4.2-7[a].</td>
</tr>
</tbody>
</table>
FIGURES (Continued)

K.6.4.2-8[a]. Stepwise rank regression analyses and selected scatterplots for time-dependent release rates (UZRA226, g/yr) and cumulative (i.e., integrated) releases (UZRA226C, g) for the movement of dissolved $^{226}$Ra from the UZ to the SZ resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository obtained with version 5.005 of the TSPA-LA Model: (a,b) regressions for UZRA226 and UZRA226C at 50,000, 200,000, and 500,000 years, and (c-h) scatterplots for UZRA226 and UZRA226C at 50,000 years .......... FK-29[a]

K.6.4.2-9[a]. Comparison of cumulative releases of dissolved $^{226}$Ra into the UZ (UZRA226C, g) and out of the UZ (UZRA226C, g) obtained with version 5.005 of the TSPA-LA Model at (a) 50,000, (b) 100,000, (c) 200,000, and (d) 600,000 years for an igneous intrusive event at 250 years that destroys all WPs in the repository .............................................. FK-31[a]

K.6.5.2-5[a]. Time-dependent release rates (SZU234, g/yr) and cumulative (i.e., integrated) releases (SZU234C, g) over 1,000,000 years for the movement of dissolved $^{234}$U across a subsurface plane at the location of the RMEI resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository obtained with version 5.005 of the TSPA-LA Model: (a,b) SZU234 and SZU234C for all (i.e., 300) sample elements, (c,d) SZU234 and SZU234C for first 50 sample elements, and (e,f) PRCCs for SZU234 and SZU234C................................. FK-32[a]

K.6.5.2-6[a]. Stepwise rank regression analyses and selected scatterplots for time-dependent release rates (SZU234, g/yr) and cumulative (i.e., integrated) releases (SZU234C, g) for the movement of dissolved $^{234}$U across a subsurface plane at the location of the RMEI resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository obtained with version 5.005 of the TSPA-LA Model: (a,b) regressions for SZU234 and SZU234C at 50,000, 200,000, and 500,000 years, and (c-h) scatterplots for SZU234 and SZU234C at 500,000 years .................................................................................................. FK-33[a]

K.6.5.2-7[a]. Comparison of cumulative releases of dissolved $^{234}$U into the SZ (UZU234C, g) and across a subsurface plane at the location of the RMEI (SZU234C, g) obtained with version 5.005 of the TSPA-LA Model at (a) 50,000, (b) 100,000, (c) 200,000, and (d) 600,000 years for an igneous intrusive event at 250 years that destroys all WPs in the repository ................................................................. FK-35[a]

K.6.5.2-8[a]. Time-dependent release rates (SZTH230, g/yr) and cumulative (i.e., integrated) releases (SZTH230C, g) over 1,000,000 years for the movement of dissolved $^{230}$Th across a subsurface plane at the location of the RMEI resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository obtained with version 5.005 of the TSPA-LA Model: (a,b) SZTH230 and SZTH230C for all (i.e., 300)
sample elements, (c,d) SZTH230 and SZTH230C for first 50 sample elements, and (e,f) PRCCs for SZTH230 and SZTH230C ................................ FK-36[a]

K6.5.2-9[a]. Stepwise rank regression analyses and selected scatterplots for time-dependent release rates (SZTH230, g/yr) and cumulative (i.e., integrated) releases (SZTH230C, g) for the movement of dissolved $^{230}$Th across a subsurface plane at the location of the RMEI resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository obtained with version 5.005 of the TSPA-LA Model: (a,b) regressions for SZTH230 and SZTH230C at 50,000, 200,00, and 500,000 years, and (c-h) scatterplots for SZTH230 and SZTH230C at 500,000 years ........................................................ FK-36[a]

K.6.5.2-10[a]. Comparison of cumulative releases of dissolved $^{230}$Th into the SZ (UZTH230C, g) and across a subsurface plane at the location of the RMEI (SZTH230C, g) obtained with version 5.005 of the TSPA-LA Model at (a) 50,000, (b) 100,000, (c) 200,000, and (d) 600,000 years for an igneous intrusive event at 250 years that destroys all WPs in the repository .................................................................................................. FK-37[a]

K6.5.2-11[a]. Time-dependent release rates (SZRA226, g/yr) and cumulative (i.e., integrated) releases (SZRA226C, g) over 1,000,000 years for the movement of dissolved $^{226}$Ra across a subsurface plane at the location of the RMEI resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository obtained with version 5.005 of the TSPA-LA Model: (a,b) SZRA226 and SZRA226C for all (i.e., 300) sample elements, (c,d) SZRA226 and SZRA226C for first 50 sample elements, and (e,f) PRCCs for SZRA226 and SZRA226C ........................................... FK-38[a]

K6.5.2-12[a]. Stepwise rank regression analyses and selected scatterplots for time-dependent release rates (SZRA226, g/yr) and cumulative (i.e., integrated) releases (SZRA226C, g) for the movement of dissolved $^{226}$Ra across a subsurface plane at the location of the RMEI resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository obtained with version 5.005 of the TSPA-LA Model: (a,b) regressions for SZRA226 and SZRA226C at 50,000, 200,000, and 500,000 years, and (c-h) scatterplots for SZRA226 and SZRA226C at 500,000 years ........................................................ FK-39[a]

K.6.5.2-13[a]. Comparison of cumulative releases of dissolved $^{226}$Ra into the SZ (UZRA226C, g) and across a subsurface plane at the location of the RMEI (SZRA226C, g) obtained with version 5.005 of the TSPA-LA Model at (a) 50,000, (b) 100,000, (c) 200,000, and (d) 600,000 years for an igneous intrusive event at 250 years that destroys all WPs in the repository .................................................................................................. FK-43[a]

K.6.6.2-5[a]. Time-dependent dose to the RMEI (DOU234, mrem/yr) over 1,000,000 years for the movement of dissolved $^{234}$U across a subsurface plane at the location of the RMEI resulting from an igneous
intrusive event at 250 years that destroys all WPs in the repository obtained with version 5.005 of the TSPA-LA Model: (a) $DOU_{234}$ for all (i.e., 300) sample elements, (b) $DOU_{234}$ for first 50 sample elements, and (c) PRCCs for $DOU_{234}$ .................................................. FK-44[a]

K.6.6.2-6[a]. Stepwise rank regression analyses and selected scatterplots for time-dependent dose to the RMEI ($DOU_{234}$, mrem/yr) for the movement of dissolved $^{234}$U across a subsurface plane at the location of the RMEI ($SZU_{234}$, g/yr) resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository obtained with version 5.005 of the TSPA-LA Model: (a) regressions for $DOU_{234}$ at 50,000, 200,000, and 500,000 years, (b,c,d) scatterplots for $DOU_{234}$ at 500,000 years, and (e) scatterplot comparing $SZU_{234}$ and $DOU_{234}$ at 500,000 years ....................................................... FK-45[a]

K.6.6.2-7[a]. Time-dependent dose to the RMEI ($DOTH_{230}$, mrem/yr) over 1,000,000 years for the movement of dissolved $^{230}$Th across a subsurface plane at the location of the RMEI resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository obtained with version 5.005 of the TSPA-LA Model: a) $DOTH_{230}$ for all (i.e., 300) sample elements, (b) $DOTH_{230}$ for first 50 sample elements, and (c) PRCCs for $DOTH_{230}$.......................................................... FK-46[a]

K.6.6.2-8[a]. Stepwise rank regression analyses and selected scatterplots for time-dependent dose to the RMEI ($DOTH_{230}$, mrem/yr) for the movement of dissolved $^{230}$Th across a subsurface plane at the location of the RMEI ($SZTH_{230}$, g/yr) resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository obtained with version 5.005 of the TSPA-LA Model: (a) regressions for $DOTH_{230}$ at 50,000, 200,000, and 500,000 years, (b,c,d) scatterplots for $DOTH_{230}$ at 500,000 years, and (e) scatterplot comparing $SZTH_{230}$ and $DOTH_{230}$ at 500,000 years................................................................. FK-47[a]

K.6.6.2-9[a]. Time-dependent dose to the RMEI ($DORA_{226}$, mrem/yr) over 1,000,000 years for the movement of dissolved $^{226}$Ra across a subsurface plane at the location of the RMEI resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository obtained with version 5.005 of the TSPA-LA Model: (a) $DORA_{226}$ for all (i.e., 300) sample elements, (b) $DORA_{226}$ for first 50 sample elements, and (c) PRCCs for $DORA_{226}$.................................................... FK-48[a]

K.6.6.2-10[a]. Stepwise rank regression analyses and selected scatterplots for time-dependent dose to the RMEI ($DORA_{226}$, mrem/yr) for the movement of dissolved $^{226}$Ra across a subsurface plane at the location of the RMEI ($SZRA_{226}$, g/yr) resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository obtained with version 5.005 of the TSPA-LA Model: (a) regressions for $DORA_{226}$ at 50,000, 200,000, and 500,000 years, (b,c,d) scatterplots for
FIGURES (Continued)

DORA226 at 50,000 years, and (e) scatterplot comparing SZRA226 and DORA226 at 50,000 years................................................................. FK-49[a]

K6.7.1-1[a]. Expected dose to RMEI (EXPDOSE, mrem/yr) over [0, 20,000 yr] for all radioactive species resulting from igneous intrusion obtained with version 5.005 of the TSPA-LA Model: (a) EXPDOSE for all (i.e., 300) sample elements, (b) EXPDOSE for first 50 sample elements, and (c) PRCCs for EXPDOSE ................................................... FK-50[a]

K6.7.1-2[a]. Stepwise rank regression analyses and selected scatterplots for expected dose to RMEI (EXPDOSE, mrem/yr) over [0, 20,000 yr] for all radioactive species resulting from igneous intrusion obtained with version 5.005 of the TSPA-LA Model: (a) regressions for EXPDOSE at 3,000, 5,000, and 10,000 years, and (b,c,d) scatterplots for EXPDOSE at 10,000 years................................................................. FK-51[a]

K.6.7.2-1[a]. Expected dose to RMEI (EXPDOSE, mrem/yr) over [0, 1,000,000 yr] for all radioactive species resulting from igneous intrusion obtained with version 5.005 of the TSPA-LA Model: (a) EXPDOSE for all (i.e., 300) sample elements, (b) EXPDOSE for first 50 sample elements, and (c) PRCCs for EXPDOSE ................................................... FK-52[a]

K.6.7.2-2[a]. Stepwise rank regression analyses and selected scatterplots for expected dose to RMEI (EXPDOSE, mrem/yr) over [0, 1,000,000 yr] for all radioactive species resulting from igneous intrusion obtained with version 5.005 of the TSPA-LA Model: (a) regressions for EXPDOSE at 50,000, 200,000, and 500,000 years, and (b,c,d) scatterplots for EXPDOSE at 500,000 years.............................................. FK-53[a]

K7.7.1-1[a]. Expected dose to RMEI (EXPDOSE, mrem/yr) over [0, 20,000 yr] for all radioactive species resulting from seismic ground motion obtained with version 5.005 of the TSPA-LA Model: (a) EXPDOSE for all (i.e., 300) sample elements, (b) EXPDOSE for first 50 sample elements, and (c) PRCCs for EXPDOSE ................................................... FK-54[a]

K7.7.1-2[a]. Stepwise rank regression analyses and selected scatterplots for expected dose to RMEI (EXPDOSE, mrem/yr) over [0, 20,000 yr] for all radioactive species resulting from seismic ground motion obtained with version 5.005 of the TSPA-LA Model: (a) regressions for EXPDOSE at 3,000, 5,000, and 10,000 years, and (b,c,d) scatterplots for EXPDOSE at 10,000 years................................................................. FK-55[a]

K7.7.2-1[a]. Expected dose to RMEI (EXPDOSE, mrem/yr) over [0, 1,000,000 yr] for all radioactive species resulting from seismic ground motion obtained with version 5.005 of the TSPA-LA Model: (a) EXPDOSE for all (i.e., 300) sample elements, (b) EXPDOSE for first 50 sample elements, and (c) PRCCs for EXPDOSE ................................................... FK-56[a]

K7.7.2-2[a]. Stepwise rank regression analyses and selected scatterplots for expected dose to RMEI (EXPDOSE, mrem/yr) over [0, 1,000,000 yr]
FIGURES (Continued)

for all radioactive species resulting from seismic ground motion obtained with version 5.005 of the TSPA-LA Model: (a) regressions for EXPDOSE at 50,000, 200,000, and 500,000 years, and (b,c,d) scatterplots for EXPDOSE at 500,000 years ........................................... FK-57[a]

K7.8.1-1[a]. Expected dose to RMEI (EXPDOSE, mrem/yr) over [0, 20,000 yr] for all radioactive species resulting from seismic fault displacement: (a) EXPDOSE for all (i.e., 300) sample elements, (b) EXPDOSE for first 50 sample elements, and (c) PRCCs for EXPDOSE ....................... FK-58[a]

K7.8.1-2[a]. Stepwise rank regression analyses and selected scatterplots for expected dose to RMEI (EXPDOSE, mrem/yr) over [0, 20,000 yr] for all radioactive species resulting from seismic fault displacement: (a) regressions for EXPDOSE at 3,000, 5,000, and 10,000 years, and (b,c,d) scatterplots for EXPDOSE at 10,000 years .................................. FK-59[a]

K7.8.2-1[a]. Expected dose to RMEI (EXPDOSE, mrem/yr) over [0, 1,000,000 yr] for all radioactive species resulting from seismic fault displacement: (a) EXPDOSE for all (i.e., 300) sample elements, (b) EXPDOSE for first 50 sample elements, and (c) PRCCs for EXPDOSE ....................... FK-60[a]

K7.8.2-2[a]. Stepwise rank regression analyses and selected scatterplots for expected dose to RMEI (EXPDOSE, mrem/yr) over [0, 1,000,000 yr] for all radioactive species resulting from seismic fault displacement: (a) regressions for EXPDOSE at 50,000, 200,000, and 500,000 years, and (b,c,d) scatterplots for EXPDOSE at 500,000 years ................... FK-61[a]

K8.1-1[a]. Expected dose to RMEI (EXPDOSE, mrem/yr) over [0, 20,000 yr] for all scenario classes obtained with version 5.005 of the TSPA-LA Model: (a) EXPDOSE for all (i.e., 300) sample elements, (b) EXPDOSE for first 50 sample elements, and (c) PRCCs for EXPDOSE .. FK-62[a]

K8.1-2[a]. Stepwise rank regression analyses and selected scatterplots for expected dose to RMEI (EXPDOSE, mrem/yr) over [0, 20,000 yr] for all scenario classes obtained with version 5.005 of the TSPA-LA Model: (a) regressions for EXPDOSE at 3,000, 5,000, and 10,000 years, and (b,c,d) scatterplots for EXPDOSE at 10,000 years ................... FK-63[a]

K8.2-1[a]. Expected dose to RMEI (EXPDOSE, mrem/yr) over [0, 1,000,000 yr] for all scenario classes obtained with version 5.005 of the TSPA-LA Model: (a) EXPDOSE for all (i.e., 300) sample elements, (b) EXPDOSE for first 50 sample elements, and (c) PRCCs for EXPDOSE .. FK-64[a]

K8.2-2[a]. Stepwise rank regression analyses and selected scatterplots for expected dose to RMEI (EXPDOSE, mrem/yr) over [0, 1,000,000 yr] for all scenario classes obtained with version 5.005 of the TSPA-LA Model: (a) regressions for EXPDOSE at 50,000, 200,000, and 500,000 years, and (b,c,d) scatterplots for EXPDOSE at 500,000 years ................. FK-65[a]
### FIGURES (Continued)

<table>
<thead>
<tr>
<th>FIGURE</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>K10-1[a]</td>
<td>Expected dose to RMEI ($EXPDOSE$, mrem/yr) over [200,000, 220,000 yr] resulting from human intrusion at 200,000 years obtained with version 5.005 of the TSPA-LA Model: (a) $EXPDOSE$ for all (i.e., 300) sample elements, (b) $EXPDOSE$ for first 50 sample elements, and (c) PRCCs for $EXPDOSE$</td>
</tr>
<tr>
<td>K10-2[a]</td>
<td>Stepwise rank regression analyses and selected scatterplots for expected dose to RMEI ($EXPDOSE$, mrem/yr) over [200,000, 220,000 yr] resulting from human intrusion at 200,000 years obtained with version 5.005 of the TSPA-LA Model: (a) $EXPDOSE$ at 201,000, 203,000, and 205,000 years, (b,c,d) scatterplots for $EXPDOSE$ at 201,000 years, and (e,f,g) scatterplots for $EXPDOSE$ at 205,000 years</td>
</tr>
<tr>
<td>K10-3[a]</td>
<td>Expected dose to RMEI ($EXPDOSE$, mrem/yr) over [220,000, 1,000,000 yr] resulting from human intrusion at 200,000 years obtained with version 5.005 of the TSPA-LA Model: (a) $EXPDOSE$ for all (i.e., 300) sample elements, (b) $EXPDOSE$ for first 50 sample elements, and (c) PRCCs for $EXPDOSE$.</td>
</tr>
<tr>
<td>K10-4[a]</td>
<td>Stepwise rank regression analyses and selected scatterplots for expected dose to RMEI ($EXPDOSE$, mrem/yr) over [220,000, 1,000,000 yr] resulting from human intrusion at 200,000 years obtained with version 5.005 of the TSPA-LA Model: (a) regressions for $EXPDOSE$ at 240,000, 500,000, and 760,000 years, and (b,c,d,e) scatterplots for $EXPDOSE$ at 500,000 years</td>
</tr>
<tr>
<td>K10-5[a]</td>
<td>Comparison of expected dose to RMEI ($EXPDOSE$, mrem/yr) over [200,000, 1,000,000 yr] resulting from human intrusion at 200,000 years obtained with versions 5.000 and 5.005 of the TSPA-LA Model at (a) 201,000, (b) 205,000, (c) 500,000, and (d) 1,000,000 years</td>
</tr>
<tr>
<td>K10-6[a]</td>
<td>Comparison of summary curves (i.e., mean and 0.05, 0.5, and 0.95 quantile) for expected dose to RMEI ($EXPDOSE$, mrem/yr) over [200,000, 1,000,000 yr] resulting from human intrusion at 200,000 years obtained with versions 5.000 and 5.005 of the TSPA-LA Model</td>
</tr>
<tr>
<td>P-20[a]</td>
<td>Expected Annual Dose versus Average Seepage Fraction for the Nominal Modeling Case for 1,000,000 Years after Repository Closure</td>
</tr>
<tr>
<td>P-21[a]</td>
<td>Expected Annual Dose versus Average Seepage Fraction for the Seismic Ground Motion Modeling Case for (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure</td>
</tr>
</tbody>
</table>
## TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.1-1[a]</td>
<td>Performance Demonstration Results for Individual Protection Standard</td>
<td>8-25[a]</td>
</tr>
<tr>
<td>8.1-2[a]</td>
<td>Performance Demonstration Results for the Separate Standards for the Protection of Groundwater</td>
<td>8-25[a]</td>
</tr>
<tr>
<td>8.1-3[a]</td>
<td>Performance Demonstration Results for the Individual Protection Standard for Human Intrusion</td>
<td>8-25[a]</td>
</tr>
<tr>
<td>8.1-4[a]</td>
<td>Uncertainty in Projections of Maximum Total Mean and Median Annual Dose (mrem) for the Individual Protection Standard</td>
<td>8-26[a]</td>
</tr>
<tr>
<td>8.1-5[a]</td>
<td>Inventories and Biosphere Dose Conversion Factors for Radionuclides Important to Total Mean Annual Dose for 10,000 Years</td>
<td>8-26[a]</td>
</tr>
<tr>
<td>8.1-6[a]</td>
<td>Uncertainty Importance Ranking as a Function of Time for Four Key TSPA-LA Model Parameters</td>
<td>8-26[a]</td>
</tr>
<tr>
<td>8.3-2[a]</td>
<td>Seepage Fractions for CDSP and CSNF Waste Packages for Combined Nominal/Early Failure Modeling Case for Glacial-Transition Climate, 2,000 to 10,000 Years</td>
<td>8-81[a]</td>
</tr>
<tr>
<td>8.3-3[a]</td>
<td>Seepage Fractions for CDSP and CSNF Waste Packages for Combined Nominal/Early Failure Modeling Case for Post-10,000-Year Period</td>
<td>8-81[a]</td>
</tr>
<tr>
<td>8.3-4[a]</td>
<td>Seepage Fractions for CDSP and CSNF Waste Packages for Seismic Ground Motion Modeling Case for Glacial-Transition Climate, 2,000 to 10,000 Years</td>
<td>8-82[a]</td>
</tr>
<tr>
<td>8.3-5[a]</td>
<td>Seepage Fractions for CDSP and CSNF Waste Packages for Seismic Ground Motion Modeling Case for Post-10,000-Year Period</td>
<td>8-82[a]</td>
</tr>
<tr>
<td>8.3-6[a]</td>
<td>Drift Wall Condensation for CSNF Waste Packages for Stage 2 and Stage 3 Condensation</td>
<td>8-83[a]</td>
</tr>
<tr>
<td>8.3-7[a]</td>
<td>Drift Wall Condensation for CDSP Waste Packages for Stage 2 and Stage 3 Condensation</td>
<td>8-84[a]</td>
</tr>
<tr>
<td>8.3-8[a]</td>
<td>Mean Seepage Rates for Waste Packages during Stage 2 and Stage 3 Condensation</td>
<td>8-84[a]</td>
</tr>
<tr>
<td>C9-1[a]</td>
<td>Impact Assessment Summary Table</td>
<td>C-3[a]</td>
</tr>
<tr>
<td>H-1[a]</td>
<td>Applicable Regulatory Requirements of 10 CFR Part 63 and NUREG-1804 Acceptance Criteria Addressed in this Document</td>
<td>H-3[a]</td>
</tr>
<tr>
<td>I-2[a]</td>
<td>Model Implementation for Included Features, Events, and Processes</td>
<td>I-3[a]</td>
</tr>
<tr>
<td>K9-1[a]</td>
<td>Summary of Selected Sensitivity Analysis Results</td>
<td>K-35[a]</td>
</tr>
<tr>
<td>P-6[a]</td>
<td>Discussion of Other Minor Implementation Errors</td>
<td>P-11[a]</td>
</tr>
<tr>
<td>P-7[a]</td>
<td>Impact Assessment Summary Table</td>
<td>P-20[a]</td>
</tr>
</tbody>
</table>
INTENTIONALLY LEFT BLANK
Section 8[a] of this addendum contains the updated results for the Total System Performance Assessment for the License Application (TSPA-LA) Model performance analyses used for evaluating the postclosure performance of the repository and its compliance with U.S. Nuclear Regulatory Commission (NRC) Proposed Rule 10 CFR 63.113 [DIRS 180319] and the performance measures defined in proposed 10 CFR 63.303 [DIRS 178394] for the individual protection standard after permanent closure in proposed 10 CFR 63.311(a)(1) and (2) [DIRS 178394], the individual protection standard for human intrusion in 10 CFR 63.321(a)(1) and (2) [DIRS 178394], and the separate standards for protection of groundwater in 10 CFR 63.331 ([DIRS 180319], Table 1). The probabilistic TSPA-LA analyses account for uncertainty and address features, events and processes (FEPs) that could affect total system performance. Volume III presents the updated results of analyses and calculations in the following areas:

- Comparison of TSPA-LA Model analyses with the performance measures defined in proposed 10 CFR 63.303 [DIRS 178394] for the individual protection standard after permanent closure in 10 CFR 63.311(a)(1) and (2) [DIRS 178394], the individual protection standard for human intrusion in 10 CFR 63.321(a)(1) and (2) [DIRS 178394], and the separate standards for protection of groundwater in 10 CFR 63.331 ([DIRS 180319], Table 1)

- System and subsystem performance analyses for the Nominal Scenario Class, including the Nominal Modeling Case; the Early Failure Scenario Class, including the Drip Shield Early Failure (EF) and Waste Package EF Modeling Cases; the Igneous Scenario Class, including Igneous Intrusion Modeling Case; and the Seismic Scenario Class, including the Seismic Ground Motion (GM) and Fault Displacement (FD) Modeling Cases

- Analyses of the capabilities and importance of the upper and lower natural barriers and the engineered barrier system (EBS) that have been identified as contributing to repository performance.

The results presented in this addendum represent an iterative process that reflects a rigorous model verification and implementation cycle.

As used in this addendum, the designator “no change” means that the reader should refer to the original text for that section or subsection of the parent TSPA-LA document. Documentation provided in this addendum consists of a combination of supplemental and revised information for the postclosure performance demonstration. In the case of revised information, the documentation presents the revised plots, tables, and discussion of the revised TSPA-LA results. The organization of the sections and subsections parallel those of the parent document. Also, section numbers, figure numbers and table numbers cited in the text with [a] refer to this addendum, while those without it refer to the section, figure or table number in the parent document. It should be noted, that some of the important aspects of the performance requirements are restated from the parent document. The material from the parent document is reproduced in this addendum to provide clarity in the presentation.
The primary output DTNs are presented in Section 8 of the parent document and in Section 8[a] of this addendum. However, for a complete listing of the output DTNs associated with the parent document and this addendum, see Appendix B and Appendix B[a].

8.1[a] CONFORMANCE WITH RADIATION PROTECTION STANDARDS

The U.S. Environmental Protection Agency (EPA) and NRC regulations for a high-level radioactive waste (HLW) repository at Yucca Mountain require that the U.S. Department of Energy (DOE) demonstrate a reasonable expectation of compliance with the applicable radiation protection standards. The proposed EPA regulation, 40 CFR Part 197 (2005 [DIRS 175755]), establishes three separate and distinct radiation protection standards for the Yucca Mountain repository. As the licensing agency, the NRC adopted the following three radiation protection standards:

- Individual Protection Standard after Permanent Closure (10 CFR 63.311 [DIRS 178394]), which considers the required characteristics of the reasonably maximally exposed individual (RMEI) as described in 10 CFR 63.312 [DIRS 180319].

- Individual Protection Standard for Human Intrusion (10 CFR 63.321 [DIRS 178394]) according to the Human Intrusion Scenario described in 10 CFR 63.322 [DIRS 180319].

- Separate Standards for Protection of Ground Water (10 CFR 63.331 [DIRS 180319]) using the representative volume specified in 10 CFR 63.332 [DIRS 180319].

The EPA and NRC proposed regulations for Individual Protection and Human Intrusion establish standards for annual doses to the RMEI corresponding to: (1) the time period of 10,000 years after closure, and (2) the time period after 10,000 years but within the period of geologic stability, defined as 1,000,000 years in 10 CFR 63.302 [DIRS 178394]. In contrast, the Separate Standards for Protection of Ground Water sets limits for annual dose and activity concentrations (i.e., radionuclide activity per unit volume) for only the 10,000-year period following repository closure. For the purpose of making performance projections for these time periods, the characteristics of the RMEI are defined in 10 CFR 63.312 [DIRS 180319], and the RMEI is taken to reside approximately 18 km (11 mi) downgradient of the repository (66 FR 55732 [DIRS 156671], III Public Comments and Responses, 3.5, p. 55750).

Detailed probabilistic projections developed for this postclosure performance demonstration are presented and explained in the subsequent sections. Tables 8.1-1[a] through 8.1-3[a] present tabulations of the maximum of total mean and median annual doses and mean activity concentrations for direct comparisons with the three radiation protection standards. The times at which the maximum total annual doses occur are also shown in Tables 8.1-1[a]. To highlight the spread in the computed distribution of expected annual doses, additional statistics are presented in Table 8.1-4[a] to better clarify the comparison with the limits of the Individual Protection Standard. Comparisons of these updated results with the results reported in the parent document are provided in Sections 8.1.1[a], 8.1.2[a], and 8.1.3[a] as part of the discussion for each radiation protection standard.

As shown in the tabular comparisons, the numerical limits prescribed in all three standards are met, with the maximum total annual doses and activity concentrations falling well below the
These numerical comparisons, however, represent only a part of the postclosure performance demonstration and many detailed calculations and graphical outputs are presented in Section 8.2[a] to elucidate the comparisons with the regulatory requirements. For the purpose of explaining the basis for a reasonable expectation of compliance, the performance demonstration for each radiation protection standard addresses the following fundamental questions regarding the TSPA of the repository and the projections of the regulatory metrics:

1. What scenario classes are considered to make performance projections, and what contribution does each scenario class make to the performance metrics?

2. What events, processes, or site characteristics modeled in the scenario classes are most important to the projections of each performance metric?

3. What barrier attributes and/or characteristics are most influential in reducing the radionuclide release rates, rate of water, or radionuclide movement?

4. What radionuclides in the nuclear waste inventory contribute the most to the annual doses and why?

5. Which uncertain input variables are most dominant in determining the uncertainty in the projected performance metrics and why?

In addition, the effect on the performance assessment of the conservatisms incorporated into the TSPA-LA Model is summarized in Section 7.7.4[a]; Section 8.4[a] summarizes the activities performed to ensure that the TSPA-LA Model and the results obtained from the model are technically sound and defensible.

The next sections describe and explain the projections that constitute the postclosure performance demonstration for the three radiation protection standards. Section 8.1.1[a] summarizes the results relevant to the Individual Protection Standard after permanent closure, Section 8.1.2[a] presents the results relevant to the Standards for the Protection of Groundwater, and Section 8.1.3[a] addresses the Individual Protection Standard for Human Intrusion. The exposure models and conversion factors used to calculate annual dose and activity concentrations in groundwater are summarized in the Biosphere Submodel description (Section 6.3.11). Conversion factors for dose to the RMEI are calculated for two general exposure scenarios, namely, groundwater and volcanic ash (SNL 2007 [DIRS 177399], Section 6.1.3).

8.1.1[a] Individual Protection Standard

No change.

8.1.1.1[a] Scenario Classes Considered and Calculation of Total Annual Doses

No change.

8.1.1.2[a] Projected Annual Doses and Major Observations

Projections of postclosure performance for comparison with the Individual Protection Standard were developed using the Monte Carlo simulation methodology, which is described in
Appendix J of the parent document. This methodology incorporates aleatory and epistemic uncertainties into the projections in two separate computational loops: (1) an outer loop that samples probability distributions for model parameters with epistemic uncertainty using the Latin hypercube sampling technique (Helton and Davis 2002 [DIRS 163475]), and (2) an inner loop that evaluates expected annual dose for each epistemic sample element by integrating over probability distributions that represent aleatory uncertainties. The methodology produces an ensemble of expected annual dose histories for each scenario class, which are then combined to obtain an ensemble of total expected annual doses. This is described by Equation 8.1.1-1 of the parent document, using the separate terms $\bar{D}_N(\tau|\theta)$ and $\bar{D}_S(\tau|\eta)$ for 10,000-year results and including the combined term $\bar{D}_N(\tau|\theta)+\bar{D}_S(\tau|\eta)$ for post-10,000-year results.

The expected annual dose histories for the RMEI are generally plotted in the form of a multi-realization plot. The mean and median values of this ensemble of total expected annual doses are termed the total mean annual dose and total median annual dose, respectively, and are the performance metrics for comparison with the Individual Protection Standard. The revised projections of postclosure performance for the 10,000-year and 1,000,000-year compliance periods were developed using TSPA-LA Model v5.005, and the results are shown on Figure 8.1-1[a] and Figure 8.1-2[a]; the plots in these figures show the multi-realization dose histories and include curves for the mean, median, 5th and 95th percentiles. For 10,000 years after closure, the maximum total mean and median annual doses to the RMEI are estimated to be about 0.24 mrem and 0.13 mrem, respectively, well below the individual protection limit of 15 mrem. Similarly, for the post-10,000-year period over the period of geologic stability, the maximum total mean and median annual doses to the RMEI are estimated to be about 2.0 mrem and 0.96 mrem, respectively. The projected maximum total median annual dose for the post-10,000 year time period is well below the proposed individual protection limit of 350 mrem.

In the parent document, results from TSPA-LA Model v5.000 showed the maximum total mean annual doses to the RMEI for 10,000 years of 0.24 mrem, and maximum total median annual doses to the RMEI for 1,000,000 years of 0.99 mrem. Thus, the corrections and changes to the TSPA-LA Model from v5.000 to v5.005 (detailed in Appendix P[a]) result in only minor changes to these performance metrics. Additional comparison of the maximum total annual doses between the two model versions is provided in Sections 7.3.1.5.8[a] and 7.3.1.5.9[a].

**Contribution to Total Annual Doses by Modeling Case**

To show the relative contribution of each of the four scenario classes to total mean annual dose, the total mean annual dose is disaggregated into the mean annual dose histories for the individual modeling cases. The four scenario classes include Nominal, Early Failure, Igneous, and Seismic. As described in the parent document, the Nominal Scenario Class (Section 6.3) is composed of one modeling case, while Early Failure (Section 6.4), Igneous (Section 6.5), and Seismic (Section 6.6) Scenario Classes each have two modeling cases. The Early Failure Scenario Class consists of the Drip Shield and Waste Package EF Modeling Cases. The Igneous Scenario Class is composed of Igneous Intrusion and Volcanic Eruption Modeling Cases. Finally, the Seismic Scenario Class is made up of the Seismic GM and Seismic FD Modeling Cases.
Projections of the expected annual doses to the RMEI for each of these modeling cases are shown on Figure 8.1-3[a]. These annual dose history curves demonstrate that:

- **Total mean annual doses** for both the 10,000-year and post-10,000-year compliance periods are dominated by contributions from the Seismic GM and Igneous Intrusion Modeling Cases, which are on the order of $10^1$ mrem for the 10,000-year period and 1 mrem for the post-10,000-year compliance period.

- **Mean annual doses** for the Waste Package EF and Seismic FD Modeling Cases are relatively small and are estimated to be on the order of $10^{-2}$ mrem or less for both the 10,000-year and post-10,000-year time periods.

- **Mean annual doses** projected for Drip Shield EF and Volcanic Eruption Modeling Cases are on the order of $10^{-3}$ mrem or less for both the 10,000-year and post-10,000-year time periods.

For each modeling case, the expected annual dose at a time $\tau$ can be conceptualized as the sum (over all possible events represented by a modeling case) of the annual dose at time $\tau$ from each event weighted by the probability of each event’s occurrence (Section 6.1.2.4 of the parent document). Thus, the relative influence on total mean annual dose of each modeling case stems from one or both of the factors involved: the dose resulting from an event and the probability of an event’s occurrence.

For the 10,000-year period after closure, the Seismic GM Modeling Case (Section 6.6.1 of the parent document) provides the majority of the total mean annual dose, with a smaller contribution from the Igneous Intrusion Modeling Case (Section 6.5.1 of the parent document). The Seismic GM Modeling Case estimates the expected annual dose resulting from the occurrence of seismic ground motion events that could damage waste packages (WPs). The dominant effect of ground motion events in the first 10,000-years after repository closure is stress-corrosion cracks of co-disposed (CDSP) WPs (Section 7.3.2.6.1.3). Within 10,000 years, the probability of a seismic event that results in damage to CDSP WPs ranges between 0 and 0.2 with a mean value of 0.07 (output DTN: MO0708CDSPSEIS.000 [DIRS 183007], FreqDamageCDSP_v5.pdf). This probability depends on the sampled value for the parameter $SCCTHRP$ (residual stress threshold [RST] for stress corrosion cracking [SCC] nucleation of Alloy 22 as a percentage of yield strength; see Section 8.1.1.6[a]). The dose resulting from a damaging seismic event includes releases from all 3,416 CDSP WPs (Section 6.6.1.2.2.2 of the parent document). However, the ensuant radionuclide releases are moderated by the relatively small damaged area on each of the WPs (Figure 6.6-13a of the parent document), which limits the radionuclide release rates from the WPs (Section 6.3.8.1 of the parent document). Appendix J, Figure J8.3-1 of the parent document, illustrates the distribution of annual doses that are projected after the occurrence of a seismic ground motion event.

In contrast, the mean probability of an igneous event is estimated to be $1.69 \times 10^{-4} = (1.69 \times 10^{-8} /\text{yr}) \times (10^4 \text{yr})$ (Table 6.5-2 of the parent document) much less than the probability of occurrence of a seismic event. The annual dose that results after an igneous event (Appendix J, Figure J7.2-1 of the parent document) is much larger than the annual dose from a seismic ground motion event, because: (1) an igneous intrusion affects all WPs (Section 6.5.1.1
of the parent document) and (2) after the intrusion, neither the drip shields (DSs) nor the WPs present any barrier to radionuclide mobilization and transport. However, as illustrated by the curves on Figure 8.1-3[a], the lower probability of occurrence of an igneous event offsets the larger annual dose from an igneous event, which explains why the expected annual dose from igneous events is less than that from seismic ground motion events.

For the post-10,000-year time period, the Igneous Intrusion Modeling Case (Section 6.5.1 of the parent document) dominates the total mean annual dose history for about 725,000 years. After that time and up to 1,000,000 years, the Igneous Intrusion and Seismic GM Modeling Cases contribute almost equally to the total mean annual dose. The probability of an igneous event remains below 0.02 before 1,000,000 years. However, as discussed in Section 8.2.4.1[a], for the post-10,000-year period, the Seismic GM Modeling Case includes the combined effects of seismic events and nominal corrosion processes on all DSs and WPs in the repository. Additional discussion of the occurrence of damage to DSs and WPs from corrosion and seismic events is provided in Section 8.3.3.2[a] and in Section 8.1.1.3[a], respectively.

The remaining four modeling cases (i.e., Drip Shield EF, Waste Package EF, Seismic FD, and Volcanic Eruption) address events that occur with varying probabilities but result in radionuclide releases from only a small number of WPs. Fault displacement events, for example, are estimated to occur with annual frequencies in the range of \(10^{-7} \text{ yr}^{-1}\), and involve on average at most a few tens of WPs (Table 6.6-1 of the parent document). The probability that at least one WP experiences an early failure is 0.442 (Section 8.2.2 of the parent document), while the expected number of early failed WPs (given that at least one early failure occurs) is estimated to be 2.46 (Section 8.2.2 of the parent document) out of 11,629 WPs (3,416 CDSPs and 8,213 CSNFs). The probability of at least one or more DS early failures is 0.017 (Section 8.2.2), and the expected number of early failed DSs (given that at least one early failure occurs) is only 1.09 (Section 8.2.2 of the parent document). Potential volcanic eruptions occur within 10,000 years with a mean probability of \((0.083) \times (1.69 \times 10^{-8}/\text{yr}) \times (10^4 \text{ yr}) = 1.4 \times 10^{-6}\) (Appendix J, Section J7.5 of the parent document) and are projected to induce releases from seven WPs or less (Table 6.5-3 of the parent document). Additional discussion and explanation of the results for each modeling case is presented in Section 8.2[a].

8.1.1.3[a] Disruptive Events Important to Postclosure Performance

As noted in Section 8.1.1.2[a], the most important events potentially affecting releases from the WPs were found to be seismic ground motion and igneous intrusion (i.e., a magmatic dike rising through the earth’s crust and intersecting the repository). Based on the FEPs screening process, the seismic and igneous events only affect the EBS. In the case of seismic or vibratory ground motion, it is possible that extensive damage and failure of the WPs and DSs could be caused by a single extreme ground motion event. More commonly, however, damage would accumulate from a sequence of small to moderate vibratory ground motions over a period of time (Section 6.6.1.2.2.2 of the parent document). However, not all WPs that experience small to moderate ground motion events are breached. In contrast, a potential igneous intrusion into the repository area is assumed to cause complete failure of all WPs and DSs in a single discrete event (Section 6.5.1.1 of the parent document).
Vibratory ground motion events can cause damage to WPs, in the form of stress corrosion cracks, ruptures or punctures of the WP outer corrosion barrier (OCB) (Section 6.6.1.1.2 of the parent document) whereas for the DS, failure occurs as the result of loading from seismic induced rock fall. In the first 10,000 years after repository closure, the primary damage caused by ground motion events is stress corrosion cracks of CDSP WPs (Section 7.3.2.6.1.3 of the parent document). The probability of a seismic event that results in damage to CDSP WPs has a mean value of about 0.07 (based on $\lambda_{CDSP} = 7.484 \times 10^{-6} \text{ yr}^{-1}$ for 10,000 years), with a maximum value of about 0.2 (based on $\lambda_{CDSP} = 2.181 \times 10^{-5} \text{ yr}^{-1}$ for 10,000 years) (output DTN: MO0708CDSPSEIS.000 [DIRS 183007], FreqDamageCDSP_v5.pdf). The probability of seismic induced DS failure before 10,000 years is approximately $1.8 \times 10^{-4}$ (DTN: MO0712PBANLNWP.000 [DIRS 184664], Lith Probability of DS Failure.pdf). Rupture and puncture of WPs are not considered because the probability that these events occur within 10,000 years is low enough and the consequence in terms of expected annual dose to the RMEI has been shown to be small enough that the contribution to the expected annual dose for the Seismic GM Modeling Case from these events is also low (Section 7.3.2.6.1.3). For this reason, the projections of mean annual dose from seismic ground motion events before 10,000 years is approximated by considering only SCC damage to CDSP WPs.

For the time period out to 1,000,000 years, seismic ground motion events have a variety of effects on the DSs and WPs. Ground motion events can lead to drift degradation and rockfall accumulation on the DS (Section 6.6.1.1 of the parent document). Subsequent failure of the DS can occur as a result of dynamic loading and deformation and/or by static loading due to accumulated rockfall. The ability of the DS to withstand the dynamic and static loading diminishes with time because general corrosion reduces the thickness of the titanium DS plate and framework. Ultimately, the DSs will fail as a result of load-induced buckling or rupture. A histogram of the time of DS plate failure for the Seismic GM Modeling Case is shown on Figure 8.1-4[a]; DS failure times for the Nominal Modeling Case (described in Section 6.3.5 of the parent document), in which DS plate failure occurs only due to general corrosion, are also shown for the purposes of comparison. As shown, the projected times of DS plate failure for the Seismic GM Modeling case are largely distributed between 100,000 years and about 300,000 years. In contrast, for the Nominal Modeling Case, DS plate failure times are distributed between 270,000 years and 340,000 years. A cumulative distribution function (CDF) for DS failure times is presented later in Section 8.3.3.2[a], along with discussion of the uncertainty in the time of DS failure. These updated histograms of DS plate failure times are nearly identical to those presented in the parent document.

As presented in Section 6.6 of the parent document, seismically induced damage of the WPs is most likely to occur from deformation or denting of the WP OCB. These localized areas of deformation or denting develop residual stresses that are susceptible to SCC. Rupture of a WP could potentially occur as a result of kinematic loading caused by package-to-pallet and/or package-to-package impacts, and a severely deformed OCB may be punctured by the sharp edges of fractured or partly degraded internal components. Generally, seismic crack damage is more likely to occur than either rupture or puncture, and CDSP WPs are more likely to be damaged than are CSNF WPs. Figure 8.1-5[a] shows summary statistics for the distribution of the probability of occurrence of seismic damage to (a) CDSP WPs and (b) CSNF WPs, estimated as the fraction of aleatory samples (futures) in which seismic damage occurs to all WPs, for each epistemic sample element. The probability of occurrence of seismic damage to CSNF WP is...
zero at and below the 5th percentile (Figure 8.1-5[a]). The distribution summarized on Figure 8.1-5[a] results from epistemic uncertainty in the RST for Alloy 22 (SCC/THRP, RST for SCC nucleation of Alloy 22 as a percentage of yield strength; see Section 8.1.1.6[a]); the spread between the quantiles indicates the strong dependence of the occurrence of seismic damage on this uncertain parameter. Section 8.1.1.6[a] provides a summary of sensitivity analyses that further illustrate this dependence.

Figure 8.1-5[a] illustrates that CSNF WPs are far less likely to be damaged by seismic events than are CDSP WPs, due to the use of the transportation, aging, and disposal (TAD) canister for CSNF, which enhances the structural integrity of these WPs. Finally, the probability that seismic events have damaged CDSP WPs increases until around 200,000 years, when DSs fail, after which only slight increases are observed. While the DSs are intact, WP damage from seismic events is determined by abstractions in which the WPs move freely beneath the DSs. In contrast, after DS failure, rubble is assumed to surround the WPs (Section 6.6.1.2.2.1 of the parent document), resulting in a significant reduction in the probabilities of damage from seismic events (output DTN: MO0708FREQCALC.000 [DIRS 183006], compare files: Rubble_Damage.pdf and DTN: MO0708CDSPSEIS.000 [DIRS 183007] FreqDamageCDSP_v5.pdf). The effects of seismic events on EBS components are described and explained in more detail in Section 8.3.3.2[a]. The revised projections of expected fraction of WPs breached by SCC are shown on Figure 8.1-5[a]; these plots reflect the corrections made to address implementation errors in two model abstractions (Appendix P, Table P-7, issues P3 and P4 in the parent document).

### 8.1.1.4[a] Multiple Barrier Processes that Contribute to Postclosure Performance

Many of the multiple barrier processes that are important to postclosure performance have been identified in previous TSPAs of the Yucca Mountain repository (Williams 2001 [DIRS 157307]). The modeling studies conducted in support of this TSPA-LA have provided additional insights and understanding, particularly with regard to individual features of natural and engineered barriers. Some of the fundamental barrier processes and characteristics that are typically influential in determining how well the system of multiple barriers isolates (i.e., contains and confines) the nuclear waste are:

- Net infiltration into the unsaturated zone (UZ) (Section 6.3.1 of the parent document) and seepage into the drifts (Section 6.3.3 of the parent document)
- Mechanical strength and corrosion rates of the WPs and DSs (Section 6.3.5 of the parent document)
- Solubilities for key radionuclides such as neptunium, uranium, and plutonium (Section 6.3.7 of the parent document)
- Radionuclide sorption onto corrosion products inside the WPs (Section 6.3.8 of the parent document)
• Diffusion-limited radionuclide releases from failed WPs (Section 6.3.8 of the parent document)

• Sorption and matrix diffusion properties of the UZ and saturated zone (SZ) underlying the repository (Sections 6.3.9 and 6.3.10 of the parent document).

With regard to infiltration and seepage, these attributes are important because they determine: (1) fraction of WPs and DSs in seeping and non-seeping environments, and (2) water flow into a failed WP and the ensuing mobilization and release of radionuclides. The strength properties of the WP OCB (i.e., Alloy 22 [UNS N06022]) and DS plate (i.e., Titanium Grade 7) and frame (i.e., Titanium Grade 29) determine their capability to withstand dynamic and static loads induced by vibratory ground motion (Section 6.6.1.2 of the parent document). General corrosion and SCC are important processes affecting WP structural integrity because they progressively reduce metal barrier thickness over a period of time. The general corrosion rate of the WP OCB is temperature-dependent, which makes the WP surface temperature an important factor. The importance of radionuclide solubilities is derived from the fact that they limit the release rates from the WPs. Solubilities of such radionuclides as neptunium, uranium, and plutonium are particularly important because they have relatively large initial inventories and produce radionuclide species that have very long half-lives. Corrosion of the WP internals produces metal oxides that provide sorption sites for a variety of fission products and actinide elements (Section 6.3.8 of the parent document). Diffusional release of radionuclides from a failed WP is a function of the breach geometry (e.g., cracks and patches) and effectively limits the rate of release to the natural barrier. The sorption properties of the volcanic tuff and alluvium layers in the UZ and SZ influence the rate of subsurface migration to the RMEI location.

Analyses of single realizations from the TSPA-LA Model (presented in Section 7.7.1[a]) illustrate these important processes and their role in isolating the nuclear waste. Although these analyses are conducted on individual modeling cases, the results for modeling cases that are important to total mean annual dose (Figure 8.1-3[a]) provide useful insights into processes and their relationships with dose outcomes. For example, the single realization analyses of the Seismic GM Modeling Case for 10,000 years (Section 7.7.1.7[a]) provide insights about impacts on repository performance for 10,000 years after closure; whereas the analyses of the Igneous Intrusion Modeling Case (Section 7.7.1.3[a]) and Seismic GM Modeling Case for 1,000,000 years (Section 7.7.1.4[a]) illustrate processes that dominate performance over 1,000,000 years. Additional discussion and interpretation of the simulation results for each of these modeling cases is provided in Section 8.2[a]. Section 8.3.3[a] provides further insight into the processes important within each of the three primary barriers.

8.1.1.5[a]  Radionuclides Important to Postclosure Performance

In general, the radionuclides in the nuclear waste that dominate the calculation of annual doses typically have one or more of the following characteristics: (1) large initial inventories in the nuclear waste, (2) moderate to high solubilities, (3) very long half-lives (e.g., \( \geq 10^5 \) years), and (4) low to non-sorbing properties. The radionuclides that become important to dose also depend on the time frame considered (i.e., 10,000 years or 1,000,000 years after closure), because of the effect of radionuclide decay on the activity concentrations. Ingrowth of radionuclides via chain decay (Figure 6.3.7-4 of the parent document) can also be an important process that determines
the role and importance of actinide elements in the actinium, uranium, neptunium, and thorium series. For groundwater releases, the basic transport processes of advection, dispersion, matrix diffusion, and sorption play an important role, as illustrated in the analyses documented in Section 7.7.1[a]. Moreover, the specific modes (e.g., dissolved and colloidal phases) of transport can also be important; the modes analyzed for each radionuclide are listed in Table 6.3.7-6[a].

The contributions of the individual radionuclides to the maximum total mean annual dose are shown on Figures 8.1-6[a] and 8.1-7[a] for 10,000 years and post-10,000 years, respectively. The relative contribution of each radionuclide is determined by its mass in the initial inventory, the intrinsic properties of each radionuclide, as well as the relative importance of the events (i.e., seismic and igneous), which lead to release of radionuclides. The radionuclide half-lives quoted in the following discussion can be found in Table 6.3.9-1[a].

**Important Radionuclides for 10,000-Year Performance Projection**—The total mean annual dose curves for individual radionuclides on Figure 8.1-6[a] show that the principal contributors to the total mean annual dose, ranked from highest to lowest, are: $^{99}$Tc (half-life $2.13 \times 10^5$ yrs), $^{14}$C (half-life $5.72 \times 10^3$ yrs), $^{239}$Pu (half-life $2.41 \times 10^4$ yrs), and $^{129}$I (half-life $1.57 \times 10^7$ yrs). Collectively, these four radionuclides account for about 87 percent of the maximum of the total mean annual dose, which occurs at 10,000 years postclosure. The dominant contributor is $^{99}$Tc, which accounts for about 51 percent of the total. Other radionuclides, notably $^{36}$Cl, $^{240}$Pu, $^{79}$Se, and $^{237}$Np, make up the remaining 13 percent of the total mean annual dose.

The fission products, $^{99}$Tc and $^{129}$I, and the activation product, $^{14}$C, collectively represent about 75 percent of the total mean annual dose. These three radionuclides are important because they are very soluble in water, do not sorb in earth materials, and in the case of $^{99}$Tc and $^{129}$I have very long half-lives relative to the 10,000-year time frame. Because technetium, iodine, and carbon radionuclides are very soluble, their release rates from the nuclear waste are limited only by: (1) the waste form degradation rates, (2) rate and extent of water saturation inside WPs, and (3) mass transport mechanisms (i.e., diffusion and/or advection) out of the WPs. The non-sorbing property is important because these radionuclides are transported from the EBS, through the natural barrier, and to the RMEI at the rate at which the groundwater naturally travels (i.e., no delay by chemical retardation). The relatively long half-lives of $^{99}$Tc and $^{129}$I, compared to 10,000 years, means that decay would not appreciably reduce their activity level.

The rate of transport of radionuclides from WPs depends on the nature and extent of damage to DSs and WPs resulting from disruptive events, the most important of which are seismic ground motion and igneous intrusion events. Before 10,000 years, roughly 70 percent of the total mean annual dose is attributable to the mean annual dose for the Seismic GM Modeling Case (Figure 8.1-3[a]), which in turn consists almost entirely of the highly soluble radionuclides $^{99}$Tc, $^{14}$C, $^{129}$I, $^{36}$Cl, and $^{79}$Se (Figure 8.2-12[a]). The predominant damage caused by vibratory ground motion is SCC of CDSW WPs (Section 7.3.2.6.1.3 of the parent document), which permits diffusion of radionuclides from WPs but not advection. In these circumstances, highly soluble radionuclides are more readily transported from the damaged WPs than are solubility-limited radionuclides such as plutonium.

The dominance of $^{99}$Tc, compared to $^{14}$C and $^{129}$I, largely stems from its WP inventory (Table 8.1-5[a]) and the fact that the predominant damage caused by vibratory ground motion is
SCC of CDSP WPs (Section 7.3.2.6.1.3 of the parent document). In CDSP WPs, the total of $^{99}\text{Tc}$ inventory on a curie per package basis is about 1,000 times that of $^{129}\text{I}$ and about 2.5 times that of $^{14}\text{C}$. Although $^{14}\text{C}$ has a larger biosphere dose conversion factor (BDCF) (Table 8.1-5[a]) than $^{99}\text{Tc}$ and $^{129}\text{I}$, it also has a relatively short half-life (5,715 years) and will experience some decay in transport. Thus, due to the larger inventory of $^{99}\text{Tc}$ and its very long half-life ($2.13 \times 10^5$), it is reasonable and consistent that $^{99}\text{Tc}$ would have greater influence than $^{14}\text{C}$ and $^{129}\text{I}$ on total mean annual dose to the RMEI.

In contrast, the Igneous Intrusion Modeling Case contributes roughly 30 percent of the total mean annual dose before 10,000 years (Figure 8.1-3[a]). The highly soluble, non-sorbing radionuclides, $^{99}\text{Tc}$, $^{14}\text{C}$, and $^{129}\text{I}$, are important to the mean annual dose for this modeling case (Figure 8.2-8a[a]) for the first 4,000 years. However, after 8,000 years, $^{239}\text{Pu}$ becomes the dominant radionuclide with $^{99}\text{Tc}$, $^{240}\text{Pu}$, and $^{129}\text{I}$ contributing to mean annual dose from igneous intrusions. Because an igneous intrusion causes complete failure of all DSs and WPs at the time of the event, radionuclides are transported from the WPs by advection as well as diffusion, resulting in the emerging importance of $^{239}\text{Pu}$. The time that $^{239}\text{Pu}$ becomes important is determined by the processes that govern the mobilization and transport of this radionuclide. The mean annual dose between 4,000 and 6,000 years shows both $^{239}\text{Pu}$ and $^{240}\text{Pu}$ emerging as dominant dose contributors (Figure 8.2-8a[a]). The comparison of Figure 8.2-8a[a] to Figure 8.1-6[a] shows that the contribution of $^{239}\text{Pu}$ to total mean annual dose at 10,000 years is due to its contribution to mean annual dose from the Igneous Intrusion Modeling Case. Thus, although the actinide $^{239}\text{Pu}$ has a relatively large initial inventory (Table 6.3.7-5 of the parent document), its contribution to total mean annual dose is limited due to the low probability of an event that can lead to its release, as well as the hydrologic and chemical processes that determine the rate of plutonium transport through the EBS and lower natural barrier. Additional discussion of these processes is provided in Sections 6.3.7 through 6.3.10 of the parent document.

**Important Radionuclides for Post-10,000-Year Performance Projection**—Figure 8.1-7[a] shows the mean annual dose for individual radionuclides for 1,000,000 years after repository closure. Between 10,000 years and 20,000 years, the dominant radionuclides are the same as those listed for the 10,000-year performance projection, namely, $^{99}\text{Tc}$, $^{14}\text{C}$, $^{239}\text{Pu}$, and $^{129}\text{I}$; however, $^{239}\text{Pu}$ becomes increasingly important with time. Between about 20,000 years until 200,000 years, the radionuclides with largest contributions to total mean annual dose are $^{239}\text{Pu}$ and $^{99}\text{Tc}$, with $^{242}\text{Pu}$ (half-life $3.75 \times 10^5$ yrs) overtaking $^{99}\text{Tc}$ around 150,000 years. Beyond 200,000 years, $^{242}\text{Pu}$ is the largest contributor, with secondary contributions from $^{99}\text{Tc}$, $^{129}\text{I}$, $^{237}\text{Np}$ (half-life $2.14 \times 10^6$ yrs), and $^{226}\text{Ra}$ (half-life 1,600 yrs). The maximum of the total mean annual dose occurs at 1,000,000 years; the radionuclides contributing to total mean annual dose, ranked from highest to lowest, are: $^{242}\text{Pu}$, $^{237}\text{Np}$, $^{226}\text{Ra}$, and $^{129}\text{I}$. These four radionuclides account for about 77 percent of the total. The actinides $^{242}\text{Pu}$ and $^{237}\text{Np}$ together represent about 52 percent of the total annual dose with $^{226}\text{Ra}$ and $^{129}\text{I}$ contributing about 25 percent.

At 1,000,000 years, the primary difference between the projections presented in this addendum (TSPA-LA Model v5.005) and the original projections documented in the parent document (TSPA-LA Model v5.000) is that $^{226}\text{Ra}$ is ranked third in the addendum projections instead of first for the post-10,000-year compliance period. This change is attributed to the correction to longitudinal dispersivity distribution, which is described in Appendix P, Section P15, of the
parent document. The explanation for persistence of the $^{226}\text{Ra}$ at 1,000,000 years is due to chain decay, which is described in the parent document.

The persistent importance of $^{99}\text{Tc}$ and $^{129}\text{I}$ to total mean annual dose throughout the 1,000,000-year time period is derived from their contributions to mean annual dose in the Seismic GM Modeling Case (Figure 8.2-12b[a]). This modeling case includes the combined effects of seismic events and nominal corrosion processes on all DSs and WPs in the repository. Because of the relatively low probability that seismic events have damaged all WPs (Figure 8.1-5[a]), it is likely that some WPs remain intact until failure occurs by nominal corrosion processes, most commonly as SCC of lid welds. As the intact WPs fail, additional quantities of $^{99}\text{Tc}$ and $^{129}\text{I}$ are released from the EBS, which results in continual releases of these radionuclides from the repository system throughout the 1,000,000 period. Additional discussion of the Seismic GM Modeling Case is provided in Section 8.2.4.1[a].

Beyond 20,000 years, two plutonium species, $^{239}\text{Pu}$ and $^{242}\text{Pu}$, are the dominant contributors to total mean annual dose, with $^{242}\text{Pu}$ supplanting $^{239}\text{Pu}$ at about 200,000 years due to radioactive decay of the latter. The contribution of these two plutonium species to total mean annual dose is due primarily to their importance in the Igneous Intrusion Modeling Case (Figure 8.2-8b[a]), where these two species comprise the dominant contributors to mean annual dose. In the Seismic GM Modeling Case, these radionuclides are minor contributors to mean annual dose until about 600,000 years, when WPs begin to fail by general corrosion. After general corrosion failures begin, seepage waters can flow through WPs with general corrosion failures, thereby increasing the quantity of plutonium released from the EBS and into the lower natural barrier. The processes that govern the mobilization and transport of plutonium are discussed in Sections 6.3.7 through 6.3.10 of the parent document.

Plutonium from degraded waste forms can be transported through the EBS either in dissolved phase, as well as sorbed reversibly or irreversibly to colloids. Plutonium releases from the EBS are moderated by sorption onto the corrosion products inside the WP (Section 6.3.8). Plutonium species are transported through groundwater in dissolved phase and reversible colloids, as well as fast (i.e., not retarded by matrix diffusion or attachment/detachment process) and slow irreversible colloids (Table 6.3.7-6), with a broad range of transport times in the SZ. Detailed probabilistic simulations of plutonium transport through the SZ in dissolved phase and as reversible colloids, neglecting effects of decay, indicate median transport times ranging from 3,000 years to greater than 1,000,000 years, with a median among all realizations of about 95,000 years (SNL 2008 [DIRS 183750], Table 6-10[a]). Simulations for the fast irreversible plutonium colloids show transport times ranging from 10 years to about 1,800 years, with a median among all realizations of about 60 years (SNL 2008 [DIRS 183750], Table 6-10[a]). However, the fast irreversible colloids represent less than one percent of all irreversible colloids (BSC 2004 [DIRS 170006], Section 6.6, Table 6-4). In contrast, for slow irreversible colloids, transport times range from 100 years to about 500,000 years, with a median among all realizations of about 4,500 years (SNL 2008 [DIRS 183750], Table 6-10[a]). The TSPA-LA Model projections indicate that the dissolved phase and reversible colloids account for the larger fraction of the contribution of plutonium to total mean annual dose.

In contrast, neptunium has higher solubilities than plutonium (compare Table 6.3.7-35 and Table 6.3.7-36 to Table 6.3.7-37 of the parent document) and travels relatively more rapidly
through the SZ; transport simulations for neptunium (neglecting effects of decay) indicate median transport times ranging from 100 years to 455,000 years, with a median among all realizations of about 3,700 years (SNL 2008 [DIRS 183750], Table 6-10[a]). However, neptunium is more retarded by sorption to corrosion products inside the WPs than is plutonium (Figure 7.7.1-8[a]), thus limiting the rate of release of neptunium from the EBS as compared to plutonium. Transport of radium is discussed in Section 8.1.2.1[a] with the presentation of results for the Groundwater Protection Standard.

8.1.1.6[a] Model Parameters Influencing Uncertainty in Expected Annual Doses

Uncertainty and sensitivity analyses were conducted to identify the TSPA-LA Model parameters that were most influential in determining the spread in the total expected annual dose projections (Appendix K[a], Section K8[a]). Those analyses identify four model parameters as having the largest influence on the overall uncertainty in the expected annual doses to the RMEI. These four parameters are: (1) occurrence rate of igneous events, \( IGRATE \); (2) RST for Alloy 22, \( SCCTHRP \); (3) temperature dependence parameter for Alloy 22 general corrosion rate, \( WDGCA22 \); and (4) the SZ ground water specific discharge, \( SZGWSPDM \). The importance ranking of these four model parameters varies with time, which is illustrated in Table 8.1-6[a]. Appendix K[a], Figure K8.1-2[a], provides information for times prior to 20,000 years, and Figure K8.2-2[a] provides information for times after 20,000 years. These model parameters are described below; Table K3-1 of the parent document provides additional details and references for each parameter. These results are very similar to that presented in the parent document.

**IGRATE**—This parameter is the estimated annual frequency of an igneous dike intersecting the repository, which is characterized as an epistemic uncertain quantity. The annual frequency of an igneous event intersecting the repository ranges from approximately \( 7.4 \times 10^{-10} \) yr to \( 5.5 \times 10^{-8} \) yr for the 5th and 95th percentiles, respectively, with a mean annual frequency of \( 1.7 \times 10^{-8} \) yr (Table 6.5-2 of the parent document). In a given epistemic realization, the annual frequency of an igneous event is sampled from the CDF for \( IGRATE \), and is used to determine the probability that an igneous event occurs.

**SCCTHRP**—This parameter is the RST for the Alloy-22 WP OCB, which is represented as an epistemically uncertain value. When the residual stress in the OCB of a WP exceeds this threshold, then SCC is presumed to occur. As explained in Section 6.3.5, residual stresses in the WP OCB result primarily from seismic ground motions that cause impacts between WPs and other WPs, emplacement pallets, or DSs; these impacts could potentially cause dynamic loads that dent the OCB, which could result in creation of residual stresses. The uncertainty in this model parameter is represented using a uniform distribution.

**WDGCA22**—This parameter relates to the temperature dependence for the general corrosion rate of the Alloy 22 WP OCB, which is characterized as an epistemically uncertain quantity. As explained in Section 6.3.5, this parameter determines the magnitude of this temperature dependence and directly influences the short-term and long-term general corrosion rates of the Alloy 22. Larger values of this parameter correspond to higher general corrosion rates while WP temperatures are above 60ºC, and to lower general corrosion rates when WP temperatures are below 60ºC. This parameter is sampled from a truncated normal distribution.
SZGWSPDM—This SZ flow and transport parameter is the logarithm of the scale factor for the groundwater specific discharge multiplier. The parameter accounts for the epistemic uncertainty in the discharge flow rate, which is used to compute advective radionuclide transport. As explained in Section 6.3.10, this uncertainty parameter is applied to all of the climate states. Values for this parameter are sampled from an empirical CDF; the technical basis for that distribution is documented in *Saturated Zone Flow and Transport Model* (SNL 2008 [DIRS 183750], Section 6.5.2.1).

More detailed discussion of the importance of these and other model parameters is given in Appendix K[a], Section K8[a].

**8.1.2[a] Groundwater Protection**

No change.

**8.1.2.1[a] Projections for Combined $^{226}$Ra and $^{228}$Ra**

The performance demonstration for this first metric of the Separate Standards for the Protection of Groundwater is based on the combined activity concentration for $^{226}$Ra and $^{228}$Ra (NRC Proposed Rule 10 CFR 63.331 [DIRS 180319], Table 1). The revised probabilistic projections of the activity concentrations are presented on Figure 8.1-9[a]. The curves shown in this figure include the estimated background level, projected mean, and 95th percentile activity concentrations of combined radium species; both the mean and 95th percentile curves exclude background. From these plots, the maximum mean groundwater concentration of combined radium at the RMEI location is estimated to be about $1.3 \times 10^{-7}$ pCi/L, or less than $10^{-6}$ pCi/L. This maximum mean activity concentration is well below the 5 pCi/L limit specified in 10 CFR 63.331 ([DIRS 180319], Table 1). This maximum activity concentration is about one order of magnitude lower than the projection presented in the parent document. This difference is primarily due to the change to the uncertainty distribution for longitudinal mass dispersivity; the description of this change is documented in Section 6.3.10.2[a].

Figure 8.1-10[a] shows the contributions of the modeling cases to the projected mean of combined radium activity concentration in groundwater, excluding natural background, for 10,000 years after closure (with the natural background level included in the graph). From the curves in this figure, it is evident that the mean of the combined radium concentration is dominated by the contribution from the Waste Package EF Modeling Case (Section 6.4.2) until 4,500 years, after which the contribution from the Seismic GM Modeling Case dominates. At 10,000 years, when the mean radium concentration obtains its maximum value, roughly 90 percent of the mean radium concentration is attributable to the Seismic GM Modeling Case. The contributions to the mean radium concentration from each modeling case parallel the importance of these modeling cases to the total mean annual dose (Section 8.1.1.2[a]). In particular, the Seismic GM Modeling Case is the dominant contributor to mean radium concentrations because this modeling case represents the potential radionuclide releases from many WPs that may be damaged by seismic events, whereas the early failure modeling cases represent radionuclide releases from the relatively few WPs that may be affected by early failures of either DSs or WPs. In both the Seismic GM and Waste Package EF Modeling Cases, radionuclide transport from the WP occurs primarily by diffusion. In contrast, early failure of DSs allows seepage waters to flow through the underlying WPs (Section 6.4.1.3 of the parent
document), which could result in greater quantity of radionuclides mobilized from each affected WPs. However, this potential for greater releases is offset by the lower expected number of affected WPs, resulting in a relatively minor contribution to the mean radium concentration from the Drip Shield EF Modeling Case.

The fundamental reasons for the very low mean radium concentrations at the RMEI location are: the relatively short half-lives of the two radium isotopes compared to their transport times in the lower natural barrier; the limited release of thorium (a parent of radium) from the EBS; and the lengthy transport time of thorium in the lower natural barrier. Both $^{228}\text{Ra}$ and $^{226}\text{Ra}$ are discussed below.

$^{228}\text{Ra}$ Activity Concentration—The chemical and nuclear properties of $^{228}\text{Ra}$, together with its very small inventory, largely explain its small contribution to the total radium activity concentrations. The radionuclide radium sorbs very strongly in the geologic media (Tables 6.3.9-2 and 6.3.10-2 of the parent document), resulting in very long transport times for $^{228}\text{Ra}$ through the lower natural barrier. Travel times for radium through the SZ alone are predominantly greater than 10,000 years (SNL 2008 [DIRS 183750], Figure 6-14[a]). However, if radium was released from WPs into the lower natural barrier, and if one postulates an unlikely hypothetical pathway with a very fast transport time, for example, of 500 years, then $^{228}\text{Ra}$, with a half-life of 5.8 years, would still experience about 86 half-lives of decay before reaching the RMEI location. This would reduce its activity by a factor of $(1/2)^{86} \sim 10^{-26}$. The initial total inventory of $^{228}\text{Ra}$ is almost entirely in the CDSP WPs (Table 6.3.7-5 of the parent document). The total activity of $^{228}\text{Ra}$ can be estimated by multiplying its initial activity per WP with the total number of CDSP WPs (Table 6.3.7-1) ($(2.39 \times 10^{-3} \text{ Ci/pkg from DOE spent nuclear fuel [DSNF]} + 3.27 \times 10^{-3} \text{ Ci/pkg from HLW}) \times 3416 \text{ pkg} = 19.3 \text{ Ci})$. After 86 half-lives of decay, the original quantity of $^{228}\text{Ra}$ would be reduced to about $2 \times 10^{13} \text{ pCi}$. After mixing this activity in the representative volume of 3,000 acre-ft, the $^{228}\text{Ra}$ activity concentration in the groundwater would be undetectable.

$^{228}\text{Ra}$ could also potentially reach the RMEI location via transport of its precursor $^{232}\text{Th}$ and subsequent ingrowth. The relevant part of the decay chain is:

$^{232}\text{Th} \text{ (half-life } 1.4 \times 10^{10} \text{ years) } \rightarrow ^{228}\text{Ra}$

Because of its extraordinarily long half-life, the $^{232}\text{Th}$ is for all practical purposes a stable element for time periods of 10,000 years. For this reason, it is conservatively assumed that $^{228}\text{Ra}$ and $^{232}\text{Th}$ are in secular equilibrium. The total initial activity of $^{232}\text{Th}$ is about the same as that of $^{228}\text{Ra}$, about 20 Ci (Table 6.3.7-5 of the parent document). However, in the Seismic GM Modeling Case, transport of thorium from the EBS to the lower natural barrier is significantly constrained by (1) the relatively small damaged area on WP surfaces with stress corrosion cracks, which limits the quantity of water available to dissolve thorium; (2) sorption of thorium onto stationary iron oxyhydroxide corrosion products within the WP; and (3) diffusion of thorium through the WP OCB. For other radionuclides (i.e., uranium and plutonium) affected by these same processes, the mean mass of these radionuclides released from the EBS over 10,000 years is only a minute fraction of the inventory (Figure 8.3-19[a] for uranium, and Figure 8.3-21[a] for plutonium). Once in the lower natural barrier, thorium is retarded more by sorption in the geologic media than is radium (Tables 6.3.9-2 and 6.3.10-2 of the parent
Simulations of thorium transport through the SZ show that (neglecting effects of decay) the median transport times (through the SZ) for thorium range from about 1,000 years to over 1,000,000 years, with the 50th percentile of the median transport times among all realizations being greater than 1,000,000 years (SNL 2008 [DIRS 183750], Table 6-10[a]).

Thus, due to the short half-life of $^{228}\text{Ra}$, the processes constraining the release of its parent, $^{232}\text{Th}$, from the EBS, and the long travel time of thorium through the lower natural barrier, it is reasonable to expect the activity concentrations for $^{228}\text{Ra}$ to show effectively undetectable levels for 10,000 years after disposal.

$^{226}\text{Ra Activity Concentration}$—The explanation for the projected low $^{226}\text{Ra}$ activity concentrations is similar to that for $^{228}\text{Ra}$. More specifically, $^{226}\text{Ra}$ is initially present in the nuclear waste, and it may also be produced as a result of the decay of uranium and thorium (Figure 6.3.7-4). The relevant part of that decay chain consists of the following:

$$^{234}\text{U} \text{ (half-life 246,000 yrs)} \rightarrow ^{230}\text{Th} \text{ (half-life 75,400 yrs)} \rightarrow ^{226}\text{Ra} \text{ (half-life 1,600 yrs)}.$$  

This decay chain is significant because it means that, even after $^{226}\text{Ra}$ depletes its initial inventory, it will be continuously replenished so long as there is a source of $^{230}\text{Th}$ and $^{234}\text{U}$. While both $^{226}\text{Ra}$ and $^{230}\text{Th}$ have relatively small initial inventories in the nuclear waste, the precursor $^{234}\text{U}$ has a significant initial inventory. Also, the large contrast in half-lives between $^{226}\text{Ra}$ and $^{230}\text{Th}$ means that $^{226}\text{Ra}$ will ultimately reach a state of secular equilibrium with $^{230}\text{Th}$. Similarly, after $^{230}\text{Th}$ depletes its initial inventory, its activity will be in secular equilibrium with its precursor $^{234}\text{U}$. The net effect is that $^{226}\text{Ra}$ will persist in the waste form for potentially millions of years.

In the Seismic GM Modeling Case, only a minute fraction of the radium present in the WP is released from the EBS (Figure 8.3-20a[a]). Radium that is released from the EBS is unlikely to reach the RMEI location in any significant quantity. As mentioned above, radium exhibits high sorption in the unsaturated tuff layers, particularly in the Zeolitic and devitrified tuff (Table 6.3.9-2 of the parent document), as well as in the volcanic units and alluvium of the SZ (Table 6.3.10-2 of the parent document). These sorption properties have the effect of greatly slowing the $^{226}\text{Ra}$ rate of migration through the lower natural barrier, to the extent that the activity concentrations of $^{226}\text{Ra}$ would diminish by simple decay before reaching the RMEI location. The breakthrough curves for radium transport through the SZ are reproduced on Figure 8.1-8; additional information is provided in Saturated Zone Flow and Transport Model Abstraction (SNL 2008 [DIRS 183750], Figure 6-14[a]). It is important to note that the breakthrough curves shown on Figure 8.1-8 do not account for decay during transport; rather, the decay is accounted for when the time-dependent releases of $^{226}\text{Ra}$ from the UZ are computed (SNL 2008 [DIRS 183750], Section 6.5). Figure 8.1-8 shows that (neglecting effects of decay) the majority of the $^{226}\text{Ra}$ transport times at the RMEI location are much greater than 10,000 years; more specifically, for individual realizations the median transport times (i.e., the times when relative mass equals 0.5 on the upper plot on Figure 8.1-8 of the parent document) in the SZ range from 18,000 years to more than 1,000,000 years (SNL 2008 [DIRS 183750], Table 6-10[a]). The 50th percentile of the median $^{226}\text{Ra}$ transport times among all realizations is estimated to be about 731,000 years (SNL 2008 [DIRS 183750], Table 6-10[a]). Due to the magnitude of these transport times, $^{226}\text{Ra}$ would experience from about 11 to more than
600 half-lives of decay before reaching the RMEI, thus reducing the activity concentration by factors \((1/2)^{11}\) to \((1/2)^{600}\). These decay factors suggest that any \(^{226}\text{Ra}\) released from the EBS would contribute negligibly to radium activity concentrations at the RMEI location.

\(^{226}\text{Ra}\) could also potentially reach the RMEI location via transport of \(^{230}\text{Th}\) and \(^{234}\text{U}\). Release of uranium from the EBS is constrained by the same processes described in the previous section for thorium. Due to the relatively long transport times for thorium (median greater than 1,000,000 years, see previous section) compared to the half-life of \(^{230}\text{Th}\) (75,400 years), any \(^{230}\text{Th}\) entering the SZ will likely experience significant decay before exiting the SZ. Any \(^{226}\text{Ra}\) produced in the SZ will be subject to chemical sorption in the geologic media, as discussed, and will also likely decay. Because of these factors, it is reasonable to expect insignificant levels of \(^{226}\text{Ra}\) activity at the RMEI location from transport and decay of its precursors.

Figure 8.3-30a[a] shows that for the Seismic GM Modeling Case at 10,000 years, the repository system retains all but a minute fraction (mean of \(10^{-10}\)) of all \(^{226}\text{Ra}\) in the initial inventory or produced by chain decay over 10,000 years. This performance is due to the relatively short half-life of \(^{226}\text{Ra}\) compared to its transport time in the SZ, the processes constraining the release of \(^{234}\text{U}\) and \(^{230}\text{Th}\) from the EBS, and the long travel time of thorium through the lower natural barrier. Thus, it is reasonable to expect the activity concentrations for \(^{226}\text{Ra}\) to show effectively undetectable levels for 10,000 years after disposal.

**Uncertainty in Radium Activity Concentrations**—The combined activity concentration for \(^{226}\text{Ra}\) and \(^{228}\text{Ra}\) are computed probabilistically using the TSPA-LA Model described in Section 6.0. Conceptually, a combined \(^{226}\text{Ra}\) and \(^{228}\text{Ra}\) activity concentration is computed for each combination of an epistemic sample element with values for aleatory parameters; an overall mean activity concentration is determined analogous to the computation of total mean dose to the RMEI (Section 8.1.1.1), although the calculation of mean activity concentration considers only a subset of the scenario classes. Thus, in principle, the calculation of a combined \(^{226}\text{Ra}\) and \(^{228}\text{Ra}\) activity concentration yields an ensemble of expected activity concentrations (where the expectation averages over aleatory uncertainty), and the relationship between epistemically uncertain variables and expected activity concentrations can be explored through sensitivity analyses.

However, for most epistemic sample elements, the expected activity concentration is effectively zero. Only a few sample elements yield numerically meaningful values, which can be observed by noting that the mean activity concentration at 10,000 years is greater than the 95th percentile (Figure 8.1-9[a]). Consequently, no sensitivity analyses are conducted for the expected activity concentration. The uncertain variables most likely to influence the uncertainty in activity concentration are those that determine the occurrence and extent of failure of WPs and the rate of radium and thorium transport through the SZ. The most important of these variables are the RST for Alloy 22 (SCCTHRP), which is important in the Seismic GM Modeling Case (Section 8.2.4.1[a]), the probability of early failure of WPs (PROBWPEF) which is important in the Waste Package EF Modeling Case (Section 8.2.2.2[a]), and the logarithm of the scale factor for the SZ groundwater specific discharge (SZGWSPDM). Additionally, sensitivity analyses of the movement of \(^{234}\text{U}\), \(^{230}\text{Th}\), and \(^{226}\text{Ra}\) through the EBS and lower natural barrier are presented in Appendix K[a], Section K.6, for the Igneous Intrusion Modeling Case. Although the Igneous Scenario Class is not considered in the calculation of mean activity concentration, results of
these analyses are informative about the influence of uncertain variables on the transport of these radionuclides. Additional discussion of the capability of the EBS and lower natural barrier to retain these radionuclides is presented in Section 8.3.3.2[a] and Section 8.3.3.3[a].

In summary, the projections for the mean activity concentrations of combined radium demonstrate with a high level of confidence that the projected level of radioactivity in a representative volume of groundwater would not exceed the numerical limit of 5 pCi/L for the combined $^{226}\text{Ra}$ and $^{228}\text{Ra}$ for the separate standards for the Protection of Groundwater (10 CFR 63.331 [DIRS 180319], Table 1).

8.1.2.2[a] Projections for Gross Alpha Activity Concentration

The performance demonstration for this metric of the Groundwater Protection Standard is based on a calculation of the mean of the gross alpha activity concentration, including $^{226}\text{Ra}$ but excluding $^{222}\text{Rn}$ and the uranium species (10 CFR 63.331 [DIRS 180319]). The TSPA Biosphere Component Model, documented in DTN: MO0702PAGWPROS.001_R0 [DIRS 179328], identifies 15 primary radionuclides that have one or more alpha emitters in their decay chain to the next tracked radionuclide. The specific alpha emitting radionuclides considered in estimating the gross alpha activity concentrations are:

- $^{210}\text{Pb}$ (half-life 22.3 years)
- $^{226}\text{Ra}$ (half-life 1,600 years)
- $^{227}\text{Ac}$ (half-life 21.8 years)
- $^{228}\text{Th}$ (half-life 1.913 years)
- $^{229}\text{Th}$ (half-life 7,300 years)
- $^{230}\text{Th}$ (half-life 75,400 years)
- $^{232}\text{Th}$ (half-life $1.4 \times 10^{10}$ years)
- $^{231}\text{Pa}$ (half-life 32,800 years)
- $^{237}\text{Np}$ (half-life $2.14 \times 10^{6}$ years)
- $^{238}\text{Pu}$ (half-life 87.7 years)
- $^{239}\text{Pu}$ (half-life 24,100 years)
- $^{240}\text{Pu}$ (half-life 6,560 years)
- $^{242}\text{Pu}$ (half-life $3.75 \times 10^{5}$ years)
- $^{241}\text{Am}$ (half-life 433 years)
- $^{243}\text{Am}$ (half-life 7,370 years).

In the calculation for gross alpha, the concentration of $^{210}\text{Pb}$ is not calculated in the TSPA-LA Model instead one alpha particle for $^{210}\text{Pb}$ has been added to that for $^{226}\text{Ra}$ resulting in a total of four alpha particles for $^{226}\text{Ra}$. Likewise, four alpha particles for $^{228}\text{Th}$ have been added to $^{232}\text{Th}$ resulting in a total of five alpha particles for $^{232}\text{Th}$.

The revised probabilistic projections for gross alpha activity concentrations over the 10,000-year time period are shown on Figure 8.1-11[a]; the activity concentration for gross alpha was calculated based on the annual mass flux of the alpha emitting radionuclides across the boundary of the accessible environment and collected in the representative groundwater volume of 3,000 acre-ft/yr. The plot in this figure shows curves for the mean and 95th percentile for gross alpha activity concentration as well as the background concentration. From the plot, the
maximum of the mean activity concentration is estimated to be $6.70 \times 10^{-5}$ pCi/L (excluding background), or effectively less than $10^{-4}$ pCi/L. This maximum value is well below the 10 CFR 63.331 ([DIRS 180319], Table 1) limit for gross alpha activity of 15 pCi/L. This revised projection is higher than the maximum activity concentration documented in the parent document by about 26 percent. This increase in projected activity concentration is due to the correction of several of the errors documented in Appendix P of the parent document; in particular, correction of the error involving iron oxyhydroxide colloid concentrations (Appendix P, Table P-7, item P18) affects the release of americium in the Drip Shield EF Modeling Case (Section 7.3.1.5.2[a]).

Figure 8.1-12[a] shows the contributions of the individual modeling cases to the mean curve for the gross alpha activity, for 10,000 years after closure (with the background level shown in the graph). Figure 8.1-12[a] shows that the mean gross alpha activity concentration is dominated by the Drip Shield EF Modeling Case until approximately 7,000 years postclosure. From 7,000 to 8,000 years, the Waste Package EF, the Drip Shield EF, and Seismic GM Modeling Case contribute approximately equally to the projected gross alpha activity concentration. Over the remaining 2,000 years, the releases from the Seismic GM modeling case become the dominant factor in the projected gross alpha activity concentration.

The primary radionuclides contributing to the mean gross alpha are solubility controlled species. The advective water flux through the WPs in the Drip Shield EF Modeling Case accounts for the early dominance of this modeling case. Both the Waste Package EF and Seismic GM Modeling Cases have intact DSs and therefore exhibit only diffusive releases from the WPs. The diffusive release mechanism in these two cases, combined with the solubility control and sorption of the alpha emitting radionuclides, accounts for the delay in their contributions to the projected gross alpha activity concentration history. Additional discussion of these modeling cases, including discussion of important radionuclides and uncertain variables, is provided in Section 8.2[a].

In summary, the projections for the mean activity concentrations of gross alpha demonstrate with a high level of confidence that the level of radioactivity in a representative volume of groundwater would not exceed the numerical limit of 15 pCi/L for the gross alpha activity (including $^{226}$Ra but excluding radon and uranium isotopes) for the Separate Standards for the Protection of Groundwater (10 CFR 63.331 [DIRS 180319], Table 1).

### 8.1.2.3[a] Projections for Combined Beta- and Photon-Emitting Radionuclides

The performance demonstration for this metric of the Separate Standards for Protection of Groundwater is based on combined beta- and photon-emitting radionuclides; both the primary beta emitters and any daughter products that decay by beta-emission are considered. The annual doses from exposure to beta-photon emitters are quantified in terms of both whole body and organ dose. The TSPA Biosphere Component Model documented in the Biosphere Model Report (SNL 2007 [DIRS 177399], Table 6.15-2), identifies a total of 19 primary radionuclides that are used to compute this groundwater protection metric.

Some of the more prominent beta emitters are: $^{14}$C, $^{36}$Cl, $^{79}$Se, $^{90}$Sr, $^{99}$Tc, $^{129}$I, $^{135}$Cs, and $^{137}$Cs. Of this set, only $^{90}$Sr and $^{137}$Cs have short half-lives (~30 years) relative to the 10,000-year time period. Some of the beta-photon emitters are daughter products of alpha and beta emitters (SNL 2007 [DIRS 177399], Table 6.15-2) such as $^{137m}$Ba (half-life 2.55 m), $^{228}$Ac (half-life
6.15 h), $^{212}\text{Pb}$ (10.64 h), and $^{208}\text{Tl}$ (half-life 3.05 m). Because these radioisotopes have half-lives ranging from minutes to several hours, they are not included in radionuclide transport calculations; however, the associated conversion factors are included in the calculation of the beta-photon dose (SNL 2007 [DIRS 177399], Section 6.15.1.2). The projections of annual doses for beta-photon emitting radionuclides are evaluated as a function of the release rates from the repository, in-growth, and groundwater transport to the accessible environment.

The revised mean annual doses to the major organs and whole body are shown on Figure 8.1-13[a] for the 10,000-year compliance period. Mean annual doses are calculated by summing the expected annual doses from each beta- and photon-emitting radionuclide and averaging over all epistemic sample elements, analogous to the calculation of total mean annual dose for the Individual Protection Standard (Section 8.1.1.1[a]). As shown on Figure 8.1-13b[a], the mean annual dose curves for the thyroid and lower large intestine overlay one another; the maximum mean annual dose for the thyroid is estimated to be 0.26 mrem and for the lower large intestine about 0.25 mrem. These maximum doses from beta-photon emitters are well below the 10 CFR 63.331 ([DIRS 180319], Table 1) limit of less than or equal to 4 mrem. The mean annual doses for the thyroid and whole body are higher than the original results presented in the parent document by 35 and 38 percent respectively, due primarily to the inclusion of $^{36}\text{Cl}$ and $^{79}\text{Se}$ in the revised calculations (Appendix P[a], Table P-7[a], item P2). Plots of the revised projected mean and 95th percentile curves are shown on Figure 8.1-14[a], which illustrate the uncertainties in the whole body and thyroid annual dose curves.

As can be seen on Figure 8.1-15[a], the largest contributions to mean annual doses to the thyroid and whole body are attributable to the Seismic GM Modeling Case. The dominance of this modeling case for the mean annual doses to the thyroid and whole body is similar to its dominance in the total mean annual dose to the RMEI, and is explained by the fact that the Seismic GM Modeling Case represents a larger expected number of breached WPs and therefore larger radionuclide releases (Section 8.1.1.2[a]). The important radionuclides for these performance metrics are similar to those for the Seismic GM Modeling Case (Section 8.2.4.1[a]). In particular, dose to the thyroid is largely attributable to $^{129}\text{I}$; while, $^{99}\text{Tc}$ contributes primarily to the alimentary tract organs, with the lower large intestine and the stomach receiving the highest doses (EPA 2002 [DIRS 175544], CD-ROM, ingestion dose coefficients for $^{99}\text{Tc}$ and $^{129}\text{I}$). Whole body dose is calculated as a weighted sum of doses to the individual organs. In this calculation, the alimentary tract organs, in particular the colon (lower large intestine) and the stomach, have large tissue weighting factors relative to other organs (proposed 40 CFR Part 197 (70 FR 49014 [DIRS 177357], Appendix A, Table A.2)). The ingestion of $^{99}\text{Tc}$ largely contributes to the dose to these organs (EPA 2002 [DIRS 175544], CD-ROM, ingestion dose coefficient for $^{99}\text{Tc}$). Thus, most of the whole body dose can be attributed to the dose from $^{99}\text{Tc}$ to the lower large intestine and the stomach, and to the dose from $^{129}\text{I}$ to the thyroid.

Because the largest contributions to the mean annual doses to the thyroid and whole body are attributable to the Seismic GM Modeling Case and result from two radionuclides that are important to the mean annual dose to the RMEI for this modeling case, the uncertain inputs important to uncertainty in organ and whole body doses are the same as those important to the mean annual dose to the RMEI. Specifically, the most important uncertain input is the RST for the Alloy-22 WP OCB ($\text{SCCTHRP}$), which largely determines the probability of WP failure from
seismic events. Additional discussion of important uncertain inputs for the Seismic GM Modeling Case is provided in Section 8.2.4.1[a].

In summary, the projections of mean annual beta-photon dose demonstrate with a high level of confidence that the annual doses to the whole body or any organ would not exceed the numerical limit of 4 mrem for groundwater protection for the combined beta- and photon-emitting doses for the separate standards for the Protection of Groundwater (10 CFR 63.331 [DIRS 180319], Table 1).

8.1.3[a] Human Intrusion Protection

No change.

8.1.3.1[a] Determination of Earliest Time for Drilling Intrusion

No change.

8.1.3.2[a] Projections of Annual Doses for Human Intrusion

To address the requirements of the Individual Protection Standard for Human Intrusion (10 CFR 63.321 [DIRS 178394]), a probabilistic TSPA methodology, analogous to that used to demonstrate performance with the Individual Protection Standard after Permanent Closure and the Separate Standards for Protection of Groundwater, was used to make projections of the annual dose following a human intrusion. The calculations of expected annual dose account for only the radionuclides released into groundwater as a consequence of the intrusion, as specified in 10 CFR 63.322(f and g) [DIRS 180319]. Based on the analysis described in Section 8.1.3.1 of the parent document, the earliest time after disposal for the drilling intrusion was taken to be 200,000 years.

As described in Section 6.1.2.5 of the parent document, a separate scenario, the Human Intrusion Scenario, is used to estimate projections of annual dose resulting from a human intrusion. This scenario considers aleatory uncertainty in the type of WP assumed to be penetrated and the location of the penetration, both within the repository footprint and in the underlying SZ. For each epistemic sample element, expected annual dose is computed by averaging over these aleatory uncertainties.

The revised probabilistic projections of expected annual dose for the Human Intrusion Scenario are presented on Figure 8.1-16[a]. The plots show the curves for the mean, median, and 5th and 95th percentiles of the distribution of expected annual doses for the period of geologic stability. The maximum of the mean annual dose to the RMEI occurs within a few thousand years after the intrusion. The maximum values of the mean and median are projected to be less than 0.013 mrem and 0.011 mrem, respectively, well below the regulatory limit of 350 mrem (10 CFR 63.321(b)(2) [DIRS 178394]). The maximum of the median annual dose, which occurs about 2500 years after the intrusion, is about 70 percent higher than the results presented in the parent document. This change is the result of correcting several implementation errors affecting this modeling case (Appendix P[a], Table P-6[a], items 6, 9, and 13) and of refining the temporal discretization for this modeling case (Section 7.3.3.6[a]). The spread of values about the median annual dose is reflected in the 5th and 95th percentiles, which are approximately
1.24 × 10^{-3} \text{ mrem} \text{ and} 2.86 × 10^{-2} \text{ mrem}, \text{ respectively, at the time when the median achieves its maximum value.}

The contribution of individual radionuclides to the total mean annual dose for the Human Intrusion Scenario for 1,000,000 years after repository closure is shown on Figure 8.1-17[a]. The Human Intrusion Modeling Case conservatively assumes that the intruded WP is intact until the intrusion. Following the intrusion, the long-lived fission products that are highly soluble and non-sorbing, such as $^{99}$Tc (half-life $2.13 \times 10^5$ yrs) and $^{129}$I (half-life $1.57 \times 10^7$ yrs), dominate the annual dose for about 50,000 years after the intrusion while the waste form is degrading, and account for about 99 percent of the maximum median annual dose. After $^{99}$Tc and $^{129}$I inventory is depleted, the long-term dose to the RMEI occurs from long-lived radionuclides that undergo sorption, primarily $^{242}$Pu (half-life $3.75 \times 10^5$ yrs) with secondary contributions from $^{135}$Cs (half-life $2.3 \times 10^6$ yrs), and $^{237}$Np (half-life $2.14 \times 10^6$ yrs). The annual dose from radionuclides that are not solubility limited, such as $^{99}$Tc, $^{129}$I, and $^{135}$Cs, is similar to those in the Waste Package EF Modeling Case because the expected number of early failed waste packages is approximately equal to 1 (Section 6.4.2.2 of the parent document) and the releases for these radionuclides out of the WP are primarily diffusive. (Note that in the Waste Package EF Modeling Case, most of the mass for these radionuclides is released prior to DS failure and thus remains primarily diffusive.) It is not feasible to compare the magnitude of $^{242}$Pu dose between the two modeling cases due to differences in transport through the EBS and UZ. For example, following DS failure in the Waste Package EF Modeling Case, the advective releases of $^{242}$Pu dominate over diffusive releases, which is not the case in the Human Intrusion Modeling Case where the diffusive releases remain dominant for the simulated time period (Section 7.7.1.6[a]). In addition, more retardation of dissolved $^{242}$Pu mass occurs in the Human Intrusion Modeling Case due to matrix diffusion along UZ borehole pathway (Section 7.7.1.6[a]).

Sensitivity analyses of the expected annual dose to the RMEI resulting from a human intrusion are presented in Appendix K[a], Section K10[a]. Due to the highly transient nature of the pulse of $^{99}$Tc and $^{129}$I, sensitivity analyses are performed within a few thousand years of the intrusion (Figures K10-1[a] and K10-2[a]) as well as many thousands of years after the intrusion (Figures K10-3[a] and K10-4[a]). The uncertain inputs that influence the uncertainty in expected annual dose during the initial pulse of $^{99}$Tc and $^{129}$I are those that influence (1) the time of arrival of the pulse (i.e., $SZGWSPDM$ (logarithm of scale factor that characterizes uncertainty in groundwater specific discharge) and $INFIL$ (pointer variable for determining infiltration condition)), (2) the effect of these radionuclides on the RMEI (i.e., $MICTC99$ (BDCF for technetium)) and (3) the total mass of these radionuclides in the nuclear waste (i.e., $CSNFMASS$ (uncertainty in radionuclide content of CSNF)). After the initial pulse of $^{99}$Tc and $^{129}$I, sensitivity analyses identify several variables with influence on the uncertainty in the long-term expected annual dose, although the analyses do not produce regression models with large $R^2$ values (Figure K10-4a[a]). These variables are primarily related to the mobilization of plutonium from the waste, and to the rate of plutonium transport through the lower natural barrier. Additional discussion is provided in Appendix K[a], Section K10[a].
In summary, these projections demonstrate with a high level of confidence that the mean annual doses to the RMEI would be well below the limits for the Individual Protection Standard for Human Intrusion (10 CFR 63.321 [DIRS 178394]). Moreover, the projections indicate that the system of multiple barriers would be sufficiently robust and resilient to limit annual doses for the prescribed Human Intrusion Scenario.
Table 8.1-1[a]. Performance Demonstration Results for Individual Protection Standard

<table>
<thead>
<tr>
<th>Time After Closure (yrs)</th>
<th>Maximum Total Mean Annual Dose (mrem)</th>
<th>Maximum Total Mean Annual Dose (yr)</th>
<th>Maximum Total Median Annual Dose (mrem)</th>
<th>Time of Maximum Total Median Annual Dose (yr)</th>
<th>Limit for Annual Dose (mrem)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10,000</td>
<td>0.24</td>
<td>10,000</td>
<td>0.13</td>
<td>~ 9,900</td>
<td>15 (mean)</td>
</tr>
<tr>
<td>1,000,000</td>
<td>2.00</td>
<td>1,000,000</td>
<td>0.96</td>
<td>~ 720,000</td>
<td>350 (median)</td>
</tr>
</tbody>
</table>

Source: Output DTN: MO0710PLOTTSF.000 [DIRS 185207],
Files: LA_v5.005_10kyr_Total_Dose_Calcs_Rev01.gsm and LA_v5.005_1Myr_Total_Dose_Calcs_Rev00.gsm.
Numerical Limits from 10 CFR 63.311(a) [DIRS 178394]

Table 8.1-2[a]. Performance Demonstration Results for the Separate Standards for the Protection of Groundwater

<table>
<thead>
<tr>
<th>Type of Limit</th>
<th>Maximum of Mean Activity Concentration or Annual Dose</th>
<th>Natural Background Level</th>
<th>Limit for Activity Concentration or Annual Dose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combined 226Ra and 228Ra</td>
<td>&lt;10-6 pCi/L</td>
<td>0.5 pCi/L</td>
<td>5 pCi/L</td>
</tr>
<tr>
<td>Gross Alpha Activity</td>
<td>&lt;10-4 pCi/L</td>
<td>0.5 pCi/L</td>
<td>15 pCi/L</td>
</tr>
<tr>
<td>Dose from Combined Beta &amp; Photon Emitting Radionuclides</td>
<td>Whole Body ~ 0.06 mrem Thyroid ~ 0.26 mrem</td>
<td>Background level excluded in regulatory requirement</td>
<td>4 mrem</td>
</tr>
</tbody>
</table>

Source: Output DTN: MO0710PLOTTSF.000 [DIRS 185207],
Files: LA_v5.005_10k_Ra_Mean_Accruals_Revs00.JNB, LA_v5.005_10Ky_Cons_Mean_Accruals_Revs00.JNB, and LA_v5.005_10kyr_Thyroid_Whole_Body_Rev00.JNB.
Numerical Limits from 10 CFR 63.331 [DIRS 180319]

Table 8.1-3[a]. Performance Demonstration Results for the Individual Protection Standard for Human Intrusion

<table>
<thead>
<tr>
<th>Time After Closure (yrs)</th>
<th>Projected Maximum Annual Dose (mrem)</th>
<th>Limit for Annual Dose (mrem)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10,000</td>
<td>0</td>
<td>15 (mean)</td>
</tr>
<tr>
<td>1,000,000</td>
<td>0.01 (median)</td>
<td>350 (median)</td>
</tr>
</tbody>
</table>

Source: Output DTN: MO0710ADTSAPO.000 [DIRS 185207],
File: LA_v5.005_HI_009000_000.gsm.
Numerical Limits from 10 CFR 63.321(b) [DIRS 178394]
Table 8.1-4[a]. Uncertainty in Projections of Maximum Total Mean and Median Annual Dose (mrem) for the Individual Protection Standard

<table>
<thead>
<tr>
<th>Time After Closure (yrs)</th>
<th>Total Mean Annual Dose</th>
<th>Total Median Annual Dose</th>
<th>5th Percentile Total Expected Annual Dose</th>
<th>95th Percentile Total Expected Annual Dose</th>
</tr>
</thead>
<tbody>
<tr>
<td>10,000</td>
<td>0.24</td>
<td>0.13</td>
<td>$6.67 \times 10^{-3}$</td>
<td>0.67</td>
</tr>
<tr>
<td>720,000</td>
<td>1.55</td>
<td>0.96</td>
<td>0.09</td>
<td>4.62</td>
</tr>
<tr>
<td>1,000,000</td>
<td>2.00</td>
<td>0.86</td>
<td>0.14</td>
<td>9.06</td>
</tr>
</tbody>
</table>

Source: Output DTN: MO0710PLOTSFIG.000 [DIRS 185207].
Files: LA_v5.005_10kyr_Total_Dose_Calcs_Rev01.gsm and LA_v5.005_1Myr_Total_Dose_Calcs_Rev00.gsm.

Table 8.1-5[a]. Inventories and Biosphere Dose Conversion Factors for Radionuclides Important to Total Mean Annual Dose for 10,000 Years

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Radionuclide Activity (Ci per Waste Package)</th>
<th>Mean BDCF (Sv/yr) / (Bq / m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CSNF</td>
<td>CDSP-DSNF</td>
</tr>
<tr>
<td>$^{99}$Tc</td>
<td>$1.30 \times 10^2$</td>
<td>2.69</td>
</tr>
<tr>
<td>$^{14}$C</td>
<td>$6.09$</td>
<td>7.98</td>
</tr>
<tr>
<td>$^{129}$I</td>
<td>$3.12 \times 10^{-1}$</td>
<td>$6.30 \times 10^{-3}$</td>
</tr>
</tbody>
</table>

Sources: Table 6.3.7-5 and SNL 2007 [DIRS 177399], Table 6.11-12.
NOTE: Activity is estimated at time of closure and does not include uncertainty in waste inventory (Section 6.3.7.1.2).

Table 8.1-6[a]. Uncertainty Importance Ranking as a Function of Time for Four Key TSPA-LA Model Parameters

<table>
<thead>
<tr>
<th>Time After Closure (yrs)</th>
<th>Two Most Important Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>3,000</td>
<td>SCCTHRP IGRATE</td>
</tr>
<tr>
<td>5,000</td>
<td>SCCTHRP IGRATE</td>
</tr>
<tr>
<td>10,000</td>
<td>SCCTHRP IGRATE</td>
</tr>
<tr>
<td>125,000</td>
<td>IGRATE SZGWSPDM</td>
</tr>
<tr>
<td>250,000</td>
<td>IGRATE SZGWSPDM</td>
</tr>
<tr>
<td>500,000</td>
<td>IGRATE WDGCA22</td>
</tr>
<tr>
<td>1,000,000</td>
<td>IGRATE WDGCA22</td>
</tr>
</tbody>
</table>

Sources: Appendix K[a], Figure K8.1-2[a] and Figure K8.2-2[a]; and output DTN: MO0801TSPAMVAC.000 [DIRS 185080]
NOTE: IGRATE = occurrence rate of igneous events
SCCTHRP = RST for Alloy 22
SZGWSPDM = logarithm of scale factor for SZ groundwater-specific discharge
WDGCA22 = temperature dependence parameter for Alloy 22 general corrosion rate
8.2[a] PROJECTIONS FOR INDIVIDUAL MODELING CASES

This section presents the probabilistic projections for the set of modeling cases used in developing the performance demonstration for the Individual Protection Standard After Permanent Closure (10 CFR 63.311 [DIRS 178394]). A subset of these modeling cases was also used for the performance demonstration for the Separate Standards for the Protection of Groundwater (NRC Proposed Rule 10 CFR 63.331, Table 1 [DIRS 180319]) (Section 8.2.1[a]). Six modeling cases are presented and explained, including: (1) Nominal (Section 6.3), (2) Waste Package EF (Section 6.4.2), (3) Drip Shield EF (Section 6.4.1), (4) Igneous Intrusion (Section 6.5.1), (5) Seismic GM (Section 6.6.1), and (6) Seismic FD (Section 6.6.1). Because the changes from TSPA-LA Model v5.000 to v5.005 only affect the analysis of the groundwater pathway, the Volcanic Eruption Modeling Case was not recalculated. Thus, the discussion presented for the Igneous Scenario Class, Section 8.2.3[a], only addresses the results of the Igneous Intrusion Modeling Case. These analyses are presented supplemental to the analyses documented in Section 8.2 of the parent document.

As noted in Section 8.1.1.2[a], the revised projections of total mean annual doses to the RMEI are largely dominated by two modeling cases: (1) Seismic GM and (2) Igneous Intrusion—as shown on Figure 8.1-3[a]. This observation is consistent with the original projections in the parent document. For the 10,000-year period, the Seismic GM Modeling Case contributed about 70 percent and the Igneous Intrusion Modeling Case contributed about 27 percent of the maximum of the total mean annual dose (i.e., 0.24 mrem). In contrast, for the post-10,000-year period, the Igneous Intrusion Modeling Case is the primary contributor with the Seismic GM Modeling Case increasing in importance as the second highest contributor to the total mean and median annual doses until approximately 750,000 years after closure. After approximately 750,000 years postclosure, the Seismic GM and Igneous Intrusion Modeling Cases contributed almost equally to the maximum median of the total annual dose (i.e., 0.96 mrem) for the post-10,000 year period.

8.2.1[a] Nominal Modeling Case

The revised projections for the Nominal Modeling Case (Section 6.3) are shown on Figure 8.2-1[a]. There is no annual dose to the REMI in the first 10,000 years, with earliest occurrence of dose around 21,000 years. In the parent document, there were no doses until about 120,000 years after closure. This change in projected doses is due to correcting the implementation error documented in Appendix P, Section P6, of the parent document. That section of the parent document describes the implementation error in the weld volume calculation, which caused an underestimation of the volume for stress corrosion cracks. Correcting this error increased the median probability of SCC occurring by a factor of about 3 for both the CDSP and CSNF WPs (Appendix P, Section P6 of the parent document). As a result, the probabilistic projections of WP breaches now exhibit a few realizations with a SCC crack penetrating the WP OCB well before 100,000 years. In particular, crack penetration occurred in less than 10,000 years in one WP in one realization because of a combination of sampled values for SCC in the closure-lid weld resulting in large initial crack length and high crack propagation velocity (output DTN: MO0801TSPAWPDS.000 [DIRS 185077] files: LA_v5.005_NC_000300_005_Conceptual_Description.doc, v5.005_rlz_182_initial_crack_length_estimate.xls). Further comparison of the TSPA-LA Model v5.005 results to the
TSPA-LA Model v5.000 results for the Nominal Modeling Case is provided in Section 7.3.1.5.1[a].

The revised maximum mean and median annual doses for the post-10,000-year period are 0.55 mrem and 0.28 mrem, respectively. The maximum mean and median annual doses to the RMEI occur at about 730,000 and 850,000 years, respectively. The two radionuclides dominating the maximum annual dose are the very soluble, long-lived, and mobile radionuclide species $^{129}\text{I}$ and $^{99}\text{Tc}$. Other second order contributors to this maximum dose value are $^{135}\text{Cs}$, $^{242}\text{Pu}$, $^{79}\text{Se}$, and $^{237}\text{Np}$ (Figure 8.2-2[a]).

As discussed in Section 6.1.2.4, expected annual dose from WPs in the Nominal Modeling Case is computed directly by the GoldSim component of the TSPA-LA Model. Aleatory uncertainty in the time and location of WP breaches, as well as the degree of damage to each WP, is implicitly accounted for in the averaging performed by the WAPDEG software and in the partitioning of WPs into representative groups (Appendix N of the parent document). The expected dose histories on Figure 8.2-1[a] are the result of a succession of three phases for releases from WPs. First, a few WP breaches may occur early, which generally consist of SCC occurring in the WP OCB closure lid welds. SCC may initiate in the lid welds once general corrosion processes have removed the layer of compressive stress produced by low plasticity burnishing (Section 6.3.5.1.2). No releases are observed before about 20,000 years after repository closure (Figure 7.7.1-74[b]). Because infiltration rates and temperatures vary across the repository footprint, the time at which a continuous thin film of adsorbed water required for diffusive radionuclide transport begins also varies (Section 6.3.8.1 of the parent document). The second phase begins at approximately 200,000 years and dominates until roughly 800,000 years, at which time SCC breaches in the WP lid welds have occurred in most realizations (Figure 8.3-6a[a]). The third phase starts around 500,000 years when WPs begin to fail by general corrosion (i.e., begin to have patch openings in the WP OCB (Figure 8.3-6b[a])). When patch openings occur, seepage waters can flow through the waste, generally resulting in larger releases of radionuclides. However, general corrosion patch penetrations occur in only a minority of WPs, and in a few realizations. Section 7.7.1.5[a] provides additional analyses of individual realizations in the Nominal Modeling Case. Finally, the step-wise increases in the annual dose curves at around 200,000 years, 300,000 years, 500,000 years and 700,000 years are due to immediate increases in the number of WP failures from SCC. These immediate increases in WP failure are caused by the coarse temporal discretization used by WAPDEG V4.07 past 100,000 years (Section 7.3.3.7[a]).

Appendix K[a] presents sensitivity analyses that determine the contribution to the uncertainty in expected annual dose that derives from individual uncertain inputs. These analyses identify the temperature dependence parameter for the Alloy 22 general corrosion rate, $WDGCA22$, as the uncertain input that largely explains the uncertainty in the expected annual dose for the Nominal Modeling Case (Figure K4.5-1[a] and Figure K4.5-2[a]). Higher values of $WDGCA22$ lead to lower general corrosion rates throughout most of the 1,000,000-year performance period. In turn, lower general corrosion rates lead to later WP failures by SCC, and to fewer WP failures by general corrosion. Several other uncertain inputs, such as the deviation from median yield strength range for the WP outer lid, $WDZOLID$, are identified as having additional, lesser effects. The effects of these other inputs are discussed in Appendix K[a], Section K4.5[a].
Sensitivity analyses for intermediate model outputs, such as the number of failed WPs, environmental and chemical conditions within the EBS, and the movement of an important radionuclide ($^{237}$Np), are presented in Appendix K, Section K4. Although these analyses are performed using results from TSPA-LA Model v5.000, the conclusions of these analyses also apply to results from TSPA-LA Model v5.005, due to the similarity in the results for the two model versions (Section 7.3.1.5.1[a]).

8.2.2[a] Early Failure Scenario Class Modeling Cases

No change.

8.2.2.1[a] Drip Shield Early Failure Modeling Case

Revised projections for the Drip Shield EF Modeling Case (Section 6.4.1) are shown on Figure 8.2-3[a] for both the (a) 10,000-year period after closure and (b) post-10,000 year time period. The expected annual dose to the RMEI for the first 10,000 years shows a maximum mean value of about $2.8 \times 10^4$ mrem and maximum median of $3.8 \times 10^3$ mrem; these maximum values occur at approximately 2,000 years and 2,200 years, respectively. Comparing these revised maximum doses with those reported in the parent document, the differences are very small. The only observable difference between the original and revised projections is that the 5th percentile curve in the revised results is slightly below $10^{-6}$ mrem level and thus does not appear on Figure 8.2-3[a]. Similarly, the maximum doses for the post-10,000-year period are also nearly identical to the original results in the parent document, including the timing of the maximums. Further comparison of the results of this modeling case is provided in Section 7.3.1.5.2[a].

The primary radionuclides that contribute to the mean annual dose for the Drip Shield EF Modeling Case are shown on Figure 8.2-4[a]. In the first 4,000 years after repository closure, three soluble and mobile radionuclides dominate dose; these radionuclides are $^{99}$Tc, $^{129}$I, and $^{14}$C. Between 4,000 and 7,000 years the contribution of $^{239}$Pu becomes increasingly important. After 7,000 years, $^{239}$Pu is the dominant contributor. The mean annual dose from $^{239}$Pu continues to increase from 7,000 years until about 40,000, creating a secondary peak in the mean annual dose curve of about $1.5 \times 10^4$ mrem. The $^{239}$Pu continues to dominate but its contribution declines until about 200,000 years, at which point $^{242}$Pu and $^{237}$Np become dominant. This pattern of dominant radionuclides and timing of the maximums are nearly identical to those discussed in Section 8.2.2.1 of the parent document.

As discussed in Section 6.1.2.4, expected annual dose from early-failed DSs is computed as a weighted average of the dose resulting from early failure of DSs overlying CDSP and CSNF WPs that may occur in different percolation subregions. Additional discussion of the processes important in determining radionuclide releases from early-failed DSs is provided in the analyses of single realizations (Section 7.7.1.2[a]).

Appendix K[a] presents sensitivity analyses that determine the contribution to the uncertainty in expected annual dose that derives from individual uncertain inputs. These analyses identify the probability for undetected defects in DSs, PROBDSEF, as the uncertain input that for the most part explains the uncertainty in the expected annual dose for the Drip Shield EF Modeling Case (Figure K5.7.1-1[a] and Figure K5.7.1-2[a] for 20,000 years; and Figure K5.7.1-3[a] and Figure K5.7.1-4[a] for 1,000,000 years). Higher values of PROBDSEF lead to a greater
expected number of early-failed DSs, which in turn exposes a larger number of WPs to seepage waters. At early times, other uncertain inputs that determine the extent and rate of seepage are identified as having lesser effects, namely, \textit{SEEPUNC} (uncertainty factor accounting for small-scale heterogeneity in fracture permeability) and \textit{SEEPPRM} (logarithm of mean fracture permeability in the lithophysal rock units). At later times, \textit{INFIL} (pointer variable for determining infiltration condition) is also important. The effects of these and other inputs are discussed in Appendix K[a], Section K5.7.1[a].

Sensitivity analyses for intermediate model outputs, such as the movement of several important radionuclides ($^{239}$Pu, $^{237}$Np, and $^{99}$Tc) through the repository system, are presented in Appendix K, Section K5. Although these analyses are performed using results from TSPA-LA Model v5.000, the conclusions of these analyses also apply to results from TSPA-LA Model v5.005, due to the similarity in the results for the two model versions (Section 7.3.1.5.2[a]).

8.2.2.2[a] Waste Package Early Failure Modeling Case

Revised projections for the Waste Package EF Modeling Case (Section 6.4.2) are shown on Figure 8.2-5[a] for both the (a) 10,000-year period after closure and (b) post-10,000 years. For the first 10,000 years after repository closure, the maximum mean and median annual doses are estimated to be about $3.7 \times 10^{-3}$ mrem and $6.2 \times 10^{-4}$ mrem; the maximum values occur between 9,000 to 10,000 years for the mean and at 2,000 years for the median. These maximum dose values are slightly higher than those reported in the parent document. The higher doses are attributed to the correction for $^{36}$Cl, $^{79}$Se, and $^{126}$Sn, which were omitted in the analyses for the parent document; the effect of the error is documented in Appendix P, Section P2.1, of the parent document. For the post-10,000-year period, the maximum mean and median annual doses reach levels of approximately $2.1 \times 10^{-2}$ mrem and $6.1 \times 10^{-3}$ mrem, respectively. The maximum mean annual dose occurs at about 12,500 years, while the maximum median annual dose occurs at about 13,500 years. The dose curves gradually decline until about 250,000 years, then increase slightly as a result of the timing of nominal failures of the DSs. When the DSs fail due to general corrosion and seepage waters begin to flow through the failed WPs, advective flow through the WPs will result in additional radionuclide mobilization and transport. By the end of the 1,000,000-year period, the projected mean annual dose falls below $10^{-3}$ mrem. These patterns and trends are nearly identical to those documented in Section 8.2.2.2 of the parent document. Further comparison of the results of this modeling case is provided in Section 7.3.1.5.3[a].

The major radionuclides that contribute to the mean annual dose for the Waste Package EF Modeling Case are shown on Figure 8.2-6[a]. In the first 10,000 years postclosure, soluble and mobile radionuclides, in particular $^{99}$Tc, $^{14}$C, and $^{129}$I, dominate the estimate of mean annual dose. In the post-10,000-year period, the maximum mean annual dose is dominated by $^{99}$Tc, $^{129}$I, and $^{239}$Pu until approximately 50,000 years, then $^{239}$Pu dominates up to about 200,000 years; thereafter, $^{242}$Pu, $^{226}$Ra, and $^{237}$Np are the primary contributors to the maximum mean annual dose. This pattern of dominant radionuclides is identical to that documented in Section 8.2.2.2 of the parent document.

As discussed in Section 6.1.2.4, expected annual dose from early-failed WPs is computed as a weighted average of the dose resulting from early failures of CDSP and CSNF WPs that may occur in different percolation subregions and that may or may not experience seepage. The
expected dose histories on Figure 8.2-5[a] are the result of a succession of four phases for releases from early-failed WPs. During the first phase, no releases are observed before about 500 years after repository closure, because WP temperatures are high enough during the first few hundred years after repository closure that insufficient water is present in the failed WPs to allow diffusive transport of radionuclides. The second phase starts when CDSP WPs begin to cool sufficiently to allow diffusion of radionuclides from the waste to the invert. Between about 500 years and 2000 years, radionuclide concentrations begin to be observed in the groundwater at the RMEI location.

The third phase begins when CSNF WPs begin to cool sufficiently that radionuclides begin to diffuse from these WPs. The initiation of release from these WPs causes the sharp increase in expected annual dose indicated on Figure 8.2-5[a] just prior to 10,000 years; additional detail is shown on Figure 7.7.1-1[a]. Because CSNF WP temperatures vary spatially in the repository, diffusive releases from these WPs begin at different times, resulting in the sequence of increases in expected annual dose. The third phase lasts until about 300,000 years, when the DSs fail due to general corrosion, and seepage waters begin to flow through the failed WPs. These advective flows result in additional radionuclide mobilization and transport, as shown by the increase in expected dose around 300,000 years. Further information about the important processes that result in radionuclide releases from early-failed WPs is provided in the analysis of single realizations in Section 7.7.1.1[a].

Appendix K[a] presents sensitivity analyses that determine the contribution to the uncertainty in expected annual dose that derives from individual uncertain inputs. These analyses identify the probability for undetected defects in WPs, PROBWPEF, as the uncertain input that predominately explains the uncertainty in the expected annual dose for the Waste Package EF Modeling Case (Figure K5.7.2-1[a] and Figure K5.7.2-2[a] for 20,000 years, and Figure K5.7.2-3[a] and Figure K5.7.2-4[a] for 1,000,000 years). Higher values of PROBWPEF lead to a greater expected number of early-failed WPs. Other uncertain inputs are identified as having lesser effects on expected annual dose, depending on the time after repository closure. In particular, at early times, the analysis identifies INFI (pointer variable for determining infiltration condition) and THERMCON (selector variable for host-rock thermal conductivity) as important, because these variables significantly influence the time at which humidity in the WP allows diffusion to begin. Before DS failure at 300,000 years, the analysis indicates an effect from ISCSNS (pointer variable that determines ionic strength for CSNF under vapor influx conditions) because this variable affects the solubility of many radionuclides. After DS failure, the analysis identifies as important several variables that determine the rate of water flow through the WPs (INFI, SEEPRRM (logarithm of mean fracture permeability in the lithophysal rock units), and SEEPUNC (uncertainty factor accounting for small-scale heterogeneity in fracture permeability)) as well as variables that determine the solubility of plutonium (EPLOWPWU (logarithm of scale factor used to characterize uncertainty in plutonium solubility)) and uranium (EPLOWNUNU (logarithm of scale factor used to characterize uncertainty in uranium solubility)). The effects of these and other inputs are discussed in Appendix K[a], Section K5.7.2[a].

Sensitivity analyses for intermediate model outputs, such as the movement of several important radionuclides (239Pu, 237Np, and 99Tc) through the repository system, are presented in Appendix K, Section K5. Although these analyses are performed using results from TSPA-LA
Model v5.000, the conclusions of these analyses also apply to results from TSPA-LA Model v5.005 due to the similarity in the results for the two model versions (Section 7.3.1.5.3[a]).

### 8.2.3[a] Igneous Scenario Class Modeling Cases

As described in Section 6.5 of the parent document, the Igneous Scenario Class consists of two modeling cases: (1) the Igneous Intrusion Modeling Case that represents the interaction of a hypothetical magmatic dike with the repository and ensuing release of radionuclides to the groundwater pathway, and (2) the Volcanic Eruption Modeling Case that represents a hypothetical volcanic eruption at the land surface and the release of radionuclides to the atmospheric pathway. Because the changes from TSPA-LA Model v5.000 to v5.005 only affect the analysis of the groundwater pathway, the Volcanic Eruption Modeling Case was not recalculated. Thus, the discussion below only addresses the results of the Igneous Intrusion Modeling Case.

#### 8.2.3.1[a] Igneous Intrusion Modeling Case

The revised projections of expected annual dose for the Igneous Intrusion Modeling Case (Section 6.5.1) are shown on Figure 8.2-7[a] for both the (a) 10,000-year period after closure and (b) post-10,000 years time period. For the first 10,000 years after repository closure, the maximum mean and median annual doses are estimated to be about $6.6 \times 10^{-2}$ mrem and $1.8 \times 10^{-2}$ mrem; both maximum values occur at the end of the 10,000 time period. These values are comparable with those documented in the parent document. For the post-10,000-year period, the maximum mean and median annual doses are estimated to be about 0.89 mrem and 0.32 mrem, respectively; both the maximum annual doses occur at 1,000,000 years. These maximum values are lower but comparable to those presented in Section 8.2.3.1 of the parent document. Further comparison of the results of this modeling case is provided in Section 7.3.1.5.4[a].

The radionuclides that contribute most to the mean annual dose are shown on Figure 8.2-8[a]. Figure 8.2-8a[a] shows that radionuclides $^{99}$Tc and $^{129}$I dominate the estimate of the mean for the first 4,000 years, and $^{239}$Pu and $^{99}$Tc dominate the estimate of the mean for the remainder of the 10,000 years postclosure period with a significant contribution from $^{240}$Pu starting from about 6,000 years. Figure 8.2-8b[a] shows that $^{239}$Pu, which is transported both in dissolved and colloidal form, dominates the maximum mean annual dose for the first 200,000 years and radionuclides $^{242}$Pu, $^{237}$Np, and $^{226}$Ra dominate the estimate of the mean for the remainder of the post-10,000-year time period. These patterns of radionuclide dominance are identical to those documented in Section 8.2.3.1 of the parent document.

As discussed in Section 6.1.2.4, the expected annual dose at time $\tau$ is computed as the sum of the contributions to dose from all possible preceding igneous events, where the dose from each event is weighted by the probability of the event’s occurrence. The results of this expectation can be seen in the different shapes of the individual radionuclide mean dose curves on Figure 8.2-8b[a]. The $^{129}$I dose curve is relatively flat and stable for the entire 1,000,000-year period (and essentially unaffected by radioactive decay because of its long half-life), whereas the dose curves for actinides with long half-lives, such as $^{235}$U, $^{238}$U, and $^{237}$Np (and their decay products) are steadily increasing. These two differing behaviors are a result of the Poisson nature of igneous activity at the repository in which the probability of an igneous event increases linearly through
time at the annual occurrence rate, with a mean of $1.7 \times 10^{-8}$ yr$^{-1}$. The steadily increasing probability of occurrence of an igneous event, combined with: (1) nearly instantaneous release of a highly soluble, non-sorbing radionuclide such as $^{129}$I, and (2) nearly constant continuous release of a solubility-limited, sorbing radionuclide such as $^{237}$Np, results in a relatively constant mean annual dose for the instantaneous release radionuclide ($^{129}$I) and an approximately linearly increasing mean annual dose for the constant release radionuclide ($^{237}$Np). The mean annual dose curve for $^{129}$I is not perfectly flat through time, as would be expected for a Poisson process, but rather begins to show a decreasing tendency in mean annual dose beginning between 200,000 and 400,000 years after repository closure because, as mentioned in Section 6.1.4.2 of the parent document, nominal corrosion processes are not included in the igneous intrusion modeling case to avoid double-counting the inventory in the calculation of total dose. Consequently, $^{129}$I that is released from the WPs due to nominal SCC and general corrosion patches is not included in the calculation of expected annual dose due to igneous intrusions, which results in lower expected annual dose at later times.

Section 7.7.1.3[a] presents analyses of individual realizations of expected annual dose, and illustrates the computation of expected annual dose from the results of simulations of single igneous intrusion events. The analyses presented in Section 7.7.1.3[a] also describe processes that determine the release of radionuclides after an intrusion, and the movement of these radionuclides through the barriers of the repository. Analyses are presented for a realization for which the expected annual dose is similar to the mean annual dose, and for a realization that has the largest value of expected annual dose, and hence significantly influences the mean annual dose.

Appendix K[a] presents sensitivity analyses that determine the contribution to the uncertainty in expected annual dose that derives from individual uncertain inputs. These analyses identify the frequency of occurrence of igneous events, $IGRATE$, as the uncertain input that primarily explains the uncertainty in the expected annual dose for the Igneous Intrusion Modeling Case (Figure K6.7.1-1[a] and Figure K6.7.1-2[a] for 20,000 years, and Figure K6.7.2-1[a] and Figure K6.7.2-2[a] for 1,000,000 years). Higher values of $IGRATE$ lead to a greater probability of occurrence of igneous events. The strong and consistent correlation between uncertainty in expected annual dose and $IGRATE$ also indicates that the uncertainty in dose resulting from igneous intrusions does not change significantly over time. Other uncertain inputs are identified as having lesser effects on expected annual dose. In particular, the analysis identifies $SZGWSPDM$ (logarithm of scale factor that characterizes uncertainty in groundwater specific discharge) and $INFIL$ (pointer variable for determining infiltration condition), because these variables significantly influence the rate of water flow through the natural barriers and hence influence the rate of radionuclide transport. Also, before 10,000 years, the analysis identifies the BDCF for technetium ($MICTC99$) as important because $^{99}$Tc is a large contributor to dose before 10,000 years. Similarly after 10,000 years, the variable $EPILOWPU$ (logarithm of scale factor used to characterize uncertainty in plutonium solubility) is important because plutonium is the dominant contributor to dose after 10,000 years. The effects of these and other inputs are discussed in Appendix K[a], Section K6.7.1[a] and Section K6.7.2[a].

Sensitivity analyses for intermediate model outputs, such as the movement of several important radionuclides ($^{239}$Pu, $^{237}$Np, and $^{99}$Tc) through the repository system, are presented in Appendix K, Section K6. Although these analyses are performed using results from TSPA-LA
Model v5.000, the conclusions of these analyses also apply to results from TSPA-LA Model v5.005 due to the similarity in the results for the two model versions (Section 7.3.1.5.4[a]).

8.2.3.2[a] Volcanic Eruption Modeling Case

No change.

8.2.4[a] Seismic Scenario Class Modeling Cases

As described in Section 6.6 of the parent document, the Seismic Scenario Class consists of two modeling cases: (1) Seismic GM Modeling Case and (2) Seismic FD Modeling Case. The following sections present and explain the revised projections for these two modeling cases.

8.2.4.1[a] Seismic Ground Motion Modeling Case

Summary of Results—The expected annual dose for the Seismic GM Modeling Case is shown on Figure 8.2-11[a]; plots are presented for both the (a) 10,000-year period and (b) post-10,000-year period. The projections of annual dose take into account aleatory uncertainty associated with characteristics of future events, such as number of events, times of events, and the event’s peak ground velocity. The mean, median, and 5th and 95th percentile curves on Figure 8.2-11[a] show uncertainty in the value of the expected annual dose, taking into account epistemic uncertainty associated with incomplete knowledge of the behavior of the physical system during and after the disruptive event. The maximum mean and median annual dose for the 10,000 year period are about 0.17 mrem and 0.07 mrem, respectively; both the maximum annual doses occur at the end of the 10,000 year time period. For the post-10,000-year period, the maximum mean and median annual doses are 1.1 mrem and 0.37 mrem, respectively; the maximum annual doses occur at 1,000,000 years and at 875,000 years, respectively. The maximum values for the 10,000 year time period are slightly lower but comparable to those documented in the parent document; however, those for the post-10,000 year period are lower by about 50 percent. The occurrence and timing of intermediate maximums in the dose curves are also different. These differences are largely attributed to the implementation correction documented in Appendix P, Sections P3 and P4, of the parent document. Further comparison of the results of this modeling case is provided in Section 7.3.1.5.6[a].

The radionuclides that contribute most to the estimate of mean annual dose are presented on Figure 8.2-12[a]. The mean dose curves on Figure 8.2-12[a] illustrate that four radionuclides, $^{99}$Tc, $^{14}$C, $^{129}$I, and $^{36}$Cl, contribute the most to the maximum mean annual dose for the 10,000-year time period. One of these species, $^{36}$Cl, was not listed in the parent document as important due to an implementation error, as documented in Appendix P, Section P2, of the parent document. As can be seen from Figure 8.2-12[b], the dominant radionuclides for the post-10,000 years are $^{99}$Tc, $^{129}$I, $^{242}$Pu, and $^{237}$Np. Two dominant radionuclide species, $^{226}$Ra and $^{79}$Se, listed in the parent document do not significantly influence the expected annual dose results presented in this addendum. The reduction of the importance of these two radionuclides in the analyses presented in this addendum can be attributed to correction for the longitudinal dispersivity used in the SZ Flow and Transport Submodel documented in Section 6.3.10[a] and Appendix P, Section P15, of the parent document.
**Expected Annual Dose for 10,000 Years**—As summarized in Section 6.1.2.4, for the first 10,000 years after repository closure, the expected annual dose at time $\tau$ is computed as the sum of the contributions to dose from all possible preceding seismic ground motion events, where the dose from each event is weighted by the probability of the event’s occurrence. The integration-based procedure used to calculate expected annual dose results in the relatively smooth results evident on Figure 8.2-11[a]. Section 7.7.1.7[a] presents analyses of an individual realization of expected annual dose for the 10,000-year period. Appendix J, Figure J8.3-3, illustrates the computation of expected annual dose from the results of simulations of single seismic events, using the simplifications to the seismic damage abstractions that are justified in Section 7.3.2.6.1.

The analyses presented in Section 7.7.1.7[a] also describe processes that determine the release of radionuclides after a damaging seismic event in the first 10,000 years, and the movement of these radionuclides through the barriers of the repository. Analyses are presented for a realization for which the expected annual dose is relatively large, and thus has a significant influence on the mean annual dose. The analyses focus on two radionuclides ($^{99}\text{Tc}$ and $^{79}\text{Se}$) that are representative of radionuclides important to the expected annual dose for this modeling case. These radionuclides are dominant contributors to the expected annual dose because they are highly soluble and thus diffuse relatively rapidly through SCC in the WP OCB, and they transport relatively rapidly through the UZ and SZ.

Appendix K[a] presents sensitivity analyses that determine the contribution to the uncertainty in expected annual dose that derives from individual uncertain inputs. These analyses identify the RST for Alloy 22, $SCCTHRP$, as the uncertain input that predominately explains the uncertainty in the expected annual dose for the Seismic GM Modeling Case for 10,000 years (Figure K7.7.1-1[a] and Figure K7.7.1-2[a]). Lower values of $SCCTHRP$ lead to a greater probability of damage occurring from seismic events, which in turn increases the expected value of the dose resulting from seismic events. Aside from $SCCTHRP$, other uncertain inputs are identified as having lesser effects on expected annual dose, although the correlations with these other inputs are not strong. At 10,000 years, the analysis identifies the BDCF for technetium ($MICTC99$) as important because $^{99}\text{Tc}$ is the largest contributor to dose at 10,000 years. Other variables with minor contributions to uncertainty include $DSNFMASS$ (scale factor characterizing uncertainty in radionuclide content of DSNF) and $HLWDRACD$ (effective rate coefficient for the dissolution of HLW glass), because of the effect these variables have on the mass of $^{99}\text{Tc}$ and its release from the waste form. The effects of these and other inputs are discussed in Appendix K[a], Section K7.7.1[a].

Sensitivity analyses for intermediate model outputs, such as the movement of several important radionuclides ($^{239}\text{Pu}$, $^{237}\text{Np}$, and $^{99}\text{Tc}$) through the repository system, are presented in Appendix K, Section K7.3 of the parent document. Although these analyses are performed using results from TSPA-LA Model v5.000, the conclusions of these analyses also apply to results from TSPA-LA Model v5.005 due to the similarity in the results for the two model versions (Sections 7.3.1.5.6[a], and 7.3.1.5.8[a]).

**Expected Annual Dose for 1,000,000 Years**—For the time period out to 1,000,000 years after repository closure, the expected annual dose at time $\tau$ is computed by a Monte Carlo simulation employing the full detail of the seismic consequences abstraction. As explained in Section 6.1.2.4, this numerical treatment is used due to the complexity of the seismic
consequences abstraction and the necessity to combine nominal corrosion processes with the effects of seismic ground motion events in this modeling case. The use of the Monte Carlo technique produces relatively noisy results as shown on Figure 8.2-11b[a]. Appendix J, Figure J8.4-1, illustrates the computation of expected annual dose from the results of simulations of single seismic events for a few epistemic sample elements, and the variability in annual dose that can result from aleatory uncertainty in the seismic events and from epistemic uncertainty in the model inputs.

The expected dose histories shown on Figure 8.2-11b[a] display two phases for the occurrence of damage to WPs. First, prior to DS failure at roughly 200,000 years (Figure 8.1-4[a]), WPs experience damage primarily from seismic events. Moreover, CDSP WPs are damaged far more frequently than are CSNF WPs (compare Figure 8.3-8a[a] for CSNF WPs and Figure 8.3-8c[a] for CDSP WPs). However, as indicated by Appendix K[a], Figure K7.7.2-2[a], the occurrence of damage to WPs in the first 200,000 years is strongly affected by the uncertainty in the RST for Alloy 22 (SCCTHRP). In particular, in sample elements with a large value of SCCTHRP, the probability of damage to CDSP WPs can be quite small (output DTN: MO0708CDSPSEIS.000 [DIRS 183007], FreqDamageCDSP_v5.pdf).

A second phase begins when the DS fails and the drifts are conceptualized to be filled with rubble. The presence of rubble significantly reduces the probability of further damage to WPs from seismic events (output DTN: MO0708FREQCALC.000 [DIRS 183006], Rubble_Damage.pdf). After DS failure, nominal corrosion processes are generally the cause of further damage to WPs, first as SCC failures of lid welds, and at much later times, as patch openings caused by general corrosion. As a consequence, at later times, the expected dose from the combination of nominal corrosion processes and seismic ground motion events (Figure 8.2-11b[a]) resembles the expected dose for the Nominal Modeling Case (Figure 8.2-1[a]). The step-wise increases in the annual dose curves at around 200,000 years, 300,000 years, 500,000 years and 700,000 years are due to immediate increases in the number of WP failures from SCC. These immediate increases in WP failure are caused by the coarse temporal discretization used by WAPDEG v4.07 past 100,000 years (Section 7.3.3.7[a]). Additional discussion of these failures is provided with the Nominal Modeling Case in Section 8.2.1[a].

Section 7.7.1.4[a] presents an analysis of a single realization of expected annual dose for the post-10,000-year period, and illustrates the progression of damage to EBS components as seismic events occur, as well as the effects of nominal corrosion processes on EBS components. Figures 8.3-7[a] through 8.3-12[a] summarize the performance of DS and WP components of the EBS subjected to ground motion and nominal corrosion processes; these results should be contrasted with Figures 8.3-4[a] through 8.3-6[a], which summarize the effects of only the nominal corrosion processes on EBS components.

Appendix K[a] presents sensitivity analyses that determine the contribution to the uncertainty in expected annual dose that derives from individual uncertain inputs. At early times, before DS failure, these analyses identify the RST for Alloy 22, SCCTHRP, as the uncertain input that predominantly explains the uncertainty in the expected annual dose (Figure K7.7.2-1[a] and Figure K7.7.2-2[a]). At later times, the temperature dependence parameter for Alloy 22 general corrosion rate, WDGCA22, is dominant. Beyond SCCTHRP and WDGCA22, the analysis identifies a number of other variables with minor contributions to uncertainty in expected annual dose.
dose. However, the lack of smoothness in the expected annual dose results due to the use of the Monte Carlo method inhibits the sensitivity analyses’ resolution of the importance of these minor contributors. In addition, the use of the Monte Carlo method precludes sensitivity analyses for intermediate model outputs, such as the movement of several important radionuclides (\(^{239}\)Pu, \(^{237}\)Np, and \(^{99}\)Tc) through the repository system, as explained in Appendix K[a], Section K7.7.2[a].

**8.2.4.2[a] Seismic Fault Displacement Modeling Case**

The revised projections of expected mean annual dose for the Seismic FD Modeling Case are shown on Figure 8.2-13[a]; the figure shows plots for both the (a) 10,000-year period and (b) post-10,000-year period. The expected annual dose takes into account aleatory uncertainty associated with characteristics associated with the number, type and location of DSs and WPs disrupted. The mean, median, and 5th and 95th percentile curves on Figure 8.2-13[a] show uncertainty in the value of the expected annual dose, taking into account epistemic uncertainty associated with incomplete knowledge of the behavior of the physical system during and after the disruptive event. For the 10,000-year postclosure period, the revised maximum mean annual dose is about \(1.5 \times 10^{-3}\) mrem, which is slightly lower than the original projection of \(1.8 \times 10^{-3}\) mrem. Similarly, for the post-10,000-year period, the revised maximum median annual dose is about \(1.1 \times 10^{-2}\) mrem, whereas the original projection was \(1.5 \times 10^{-2}\) mrem. Further comparison of the results of this modeling case is provided in Section 7.3.1.5.7[a].

The individual radionuclide contributions to mean annual dose are shown in the results presented on Figure 8.2-14[a] for both the 10,000-year and post-10,000-year period after closure. The plot for the 10,000-year period (Figure 8.2-14[a]) shows that \(^{99}\)Tc and \(^{129}\)I dominate the dose for approximately the first 5,000 years after closure and \(^{99}\)Tc and \(^{239}\)Pu dominate the dose for the subsequent 5,000 years. Figure 8.2-14b[a] shows that \(^{239}\)Pu dominates the mean annual dose for the post-10,000-year time period until approximately 200,000 years postclosure. After approximately 200,000 years and until 1,000,000 years postclosure, the radionuclides contributing most to the mean annual dose are \(^{242}\)Pu, \(^{237}\)Np, and \(^{226}\)Ra. These patterns of radionuclide contribution and dominance are identical to those documented in Section 8.2.4.2 of the parent document.

Analyses of single realizations from the Seismic FD Modeling Case are not presented in Section 7.7.1, because this modeling case is a relatively low contributor to the total expected dose (Figure 8.1-3[a]), and because the processes important to radionuclide releases are examined in the analyses for the Waste Package EF Modeling Case (Section 7.7.1.1[a]) and Drip Shield EF Modeling Case (7.7.1.2[a]). The expected annual dose at time \(\tau\) is computed as the sum of the contributions to dose from all possible preceding fault displacement events, where the dose from each event is weighted by the probability of the event’s occurrence (Section 6.1.2.4). As indicated by Equation 6.1.2-25, each realization of expected annual dose is implicitly averaged over the aleatory uncertainty in the number, type and location of WPs damaged by fault displacement. Specifically, the GoldSim component of the TSPA-LA Model computes the dose resulting from fault displacement damage to 100 WPs of each type distributed proportionally among the percolation subregions, and within each subregion, into either seeping or non-seeping conditions. The EXDOC component (EXDOC_LA V2.0, STN: 11193-2.0-00 [DARS 182102]) of the TSPA-LA Model computes expected annual dose by scaling these results to the expected number of WPs of each type. This implementation is chosen for numerical efficiency. Because
of this implementation, each annual dose history computed by the GoldSim component involves WPs placed in both seeping and non-seeping conditions. Therefore, the analyses presented in Section 7.7.1.2[a] for the Drip Shield EF Modeling Case provide insight into the processes important to radionuclide releases from WPs affected by fault displacement that are in seeping conditions. Similarly, the analyses presented in Section 7.7.1.1[a] for the Waste Package EF Modeling Case provide insight into the processes important to radionuclide releases from WPs affected by fault displacement that are in non-seeping conditions.

Appendix K[a] presents sensitivity analyses that determine the contribution to the uncertainty in expected annual dose that derives from individual uncertain inputs. These analyses identify several variables with moderate influence on the uncertainty in the expected annual dose for the Seismic FD Modeling Case (Figure K7.8.1-1[a] and Figure K7.8.1-2[a] for 10,000 years; and Figure K7.8.2-1[a] and Figure K7.8.2-2[a] for 1,000,000 years). For the first 10,000 years after repository closure, the uncertain inputs with the strongest influence on the uncertainty in expected annual dose are variables that influence the rate of water flow and the dose from $^{99}$Tc. In particular, the analysis identifies $SZGWSPDM$ (logarithm of scale factor that characterizes uncertainty in groundwater specific discharge) and $INFIL$ (pointer variable for determining infiltration condition) as important, because these variables significantly influence the rate of water flow through the natural barriers and, hence, influence the rate of radionuclide transport. Also, before 10,000 years, the analysis identifies the BDCF for technetium ($MICTC99$) as important because $^{99}$Tc is a large contributor to dose before 10,000 years. However, the regression model (Figure 7.8.1-2[a]) that results from considering these three variables explains only part of the uncertainty in expected annual dose; a number of other uncertain inputs are identified as having lesser effects and incrementally improving the regression model.

After 10,000 years, the uncertain inputs with the strongest influence on the uncertainty in expected annual dose are variables that influence the rate of water flow, along with uncertainty in plutonium solubility. In particular, the analysis again identifies the variables $SZGWSPDM$ and $INFIL$, along with $WPFLUX$ (WP flux splitting factor) and $SEEPPRM$ (logarithm of mean fracture permeability in the lithophysal rock units) as important due to the effects that these variables have on water flow through the EBS and natural barriers. Also, the variable $EPILOWPU$ (logarithm of scale factor used to characterize uncertainty in plutonium solubility) is important because plutonium is the dominant contributor to dose after 10,000 years. However, the regression model (Figure K7.8.2-2[a]) that results from considering these variables explains only part of the uncertainty in expected annual dose; a number of other uncertain inputs are identified as having lesser effects and incrementally improving the regression model.

Sensitivity analyses for intermediate model outputs, such as the movement of radionuclides through the repository system, are not presented for the Seismic FD Modeling Case. Insight into the processes important to radionuclide movement can be obtained from the analyses of radionuclide movement for early failure modeling cases, presented in Appendix K, Section K5. Although these analyses are performed using results from TSPA-LA Model v5.000, the conclusions of these analyses also apply to results from TSPA-LA Model v5.005 due to the similarity in the results for the two model versions (Section 7.3.1.5.7[a]).
8.3[a] DESCRIPTION OF MULTIPLE BARRIER CAPABILITY

As shown on Figure 8-1 of the parent document, the repository system is composed of three primary barriers that include: (1) upper natural barrier (Section 8.3.2.1), (2) engineered barrier system (EBS) (Section 8.3.2.2), and (3) lower natural barrier (Section 8.3.2.3). In this section, both qualitative and quantitative descriptions are presented to explain the performance capabilities of the multiple barriers. As used here, barrier capability is defined as the extent to which a barrier performs its functions. Barrier functions are two-fold: (1) prevent or substantially reduce the water from contacting the waste, and (2) prevent or substantially reduce the release of radionuclides from the repository to the accessible environment.

The analyses presented in this section are intended to address the NRC requirements of 10 CFR 63.115 [DIRS 180319] for multiple barriers. Section 8.3.3[a] of this addendum has been added to the material presented in the parent document. Section 8.3.3[a] contains a quantitative discussion of the capabilities of the individual barriers. This section should be utilized with the material in Section 8.3 of the parent document to provide a complete discussion of the performance characteristics and capabilities of the individual barriers.

8.3.1[a] Radionuclides Selected to Demonstrate Multiple Barrier Capability

As described in Section 8.3.1 of the parent document, twelve radionuclides were selected for analysis in the demonstration of barrier capability. The radionuclides were grouped into the five categories shown below (descriptions slightly modified from parent document):

1. Large initial inventory and short half-life: $^{137}$Cs, $^{90}$Sr, $^{241}$Am, and $^{240}$Pu
2. Highly soluble, non-sorbing, long half-life, and major contributor to dose: $^{99}$Tc
3. Solubility limited, moderately to strongly sorbing, long half-life, transported in dissolved and colloidal phases, and important contributor to dose: $^{239}$Pu and $^{242}$Pu
4. Moderately soluble, weakly sorbing in the lower natural barrier, very long half-life, and transported in dissolved phase: $^{237}$Np and $^{234}$U
5. Strongly sorbed, and contributes to or is produced by decay chain ingrowth: $^{243}$Am, $^{230}$Th, and $^{226}$Ra.

These twelve radionuclides represent a broad range of radioactive decay properties, geochemical behavior, BDCFs, and transport characteristics in geologic media. Because of these diverse properties, these twelve radionuclides provide a means of examining the performance characteristics of the natural and engineered barriers. The inventory decay histories for these twelve radionuclides are shown on Figure 8.3-1[a] for the two compliance periods (i.e., 10,000 years and post-10,000 years); Figure 8.3-2[a] shows the fraction of total activity attributed to each radionuclide.

8.3.2[a] Identification of Barriers for Yucca Mountain Repository

No change.
8.3.2.1[a] Upper Natural Barrier

No change.

8.3.2.2[a] Engineered Barrier System

No change.

8.3.2.3[a] Lower Natural Barrier

No change.

8.3.3[a] Demonstration of Multiple Barrier Capability

While the applicable NRC regulation (10 CFR 63.115 [DIRS 180319]) does not require performance analyses of individual barriers, a model-based demonstration of barrier capability was considered central to explaining and supporting the compliance demonstrations presented earlier in Section 8.1 of the parent document, as well as the revised results in Section 8.1[a]. In the case of the upper natural barrier, the performance characteristics have been analyzed using detailed process-level models (SNL 2007 [DIRS 182145] and SNL 2007 [DIRS 184614]). Performance analyses of the EBS and the lower natural barrier, however, were conducted using the TSPA-LA Model, which is described in Section 6 of the parent document.

In this section, TSPA-LA Model simulation results are presented that provide insights to the intrinsic characteristics of individual barriers that would contribute significantly to the isolation (i.e., containment and confinement) of the nuclear waste. Probabilistic projections for fundamental barrier performance and characteristics are presented that clearly illustrate effectiveness of three principal barriers. As described in Section 8.3 of the parent document, two demonstration modeling cases are used to quantify the capability for the three primary barriers. These demonstration modeling cases are: (1) combined Nominal/Early Failure Modeling Case (representative of the absence of disruptive events), and (2) Seismic GM Modeling Case (representative of the presence of disruptive events). With regard to the combined Nominal/Early Failure Modeling Case, the early failures include both DSs and WPs (Section 6.4.1 and 6.4.2 of the parent report). Because nominal corrosion processes alter the response of the engineered barrier components to seismic events, nominal corrosion processes are also included in the Seismic GM Modeling Case calculation.

8.3.3.1[a] Upper Natural Barrier

The hydrologic effectiveness of the Yucca Mountain upper natural barrier has been evaluated in recent modeling studies of: (1) net infiltration through the surficial soil, (2) three-dimensional flow and deep percolation, and (3) local flow processes determining drift seepage. The recent study of net infiltration (SNL 2008 [DIRS 182145]) provided boundary conditions for the study of three-dimensional (3-D) flow (SNL 2007 [DIRS 184614]) in the unsaturated tuff unit overlying the repository. Based on the UZ flow fields, probabilistic analyses of drift seepage were conducted to study the processes determining drift seepage and to project drift seepage for intact and collapsed drift conditions (SNL 2007 [DIRS 181244]). Collectively, these flow modeling studies and projections provide the basis to describe how well the upper natural barrier
prevents or substantially reduces the rate of water flow through the UZ and to the repository. The effectiveness of the upper natural barrier is described using the following three relative metrics:

1. Net infiltration into the bedrock as a percentage of precipitation rate for the 10,000-year compliance period

2. Spatially averaged drift seepage rate as a percentage of percolation flux (percolation rates are prescribed for the post-10,000-year compliance period in NRC Proposed Rule 10 CFR 63.342(c)(2) [DIRS 178394])

3. Seepage fraction for each percolation subregion for the 10,000-year and post-10,000-year compliance periods.

The first barrier capability metric provides a quantitative demonstration of the effectiveness of the topography and surficial soils. The second and third metrics focus on the effectiveness of the UZ tuff units above and inclusive of the repository horizon. The quantification of these relative metrics is presented for each of the three climate states (BSC 2004 [DIRS 170002], Section 7.1) of the 10,000-year compliance period, namely: (1) present-day (from 0 to 600 years), (2) monsoon (from 600 to 2,000 years), and (3) glacial-transition (from 2,000 to 10,000 years). For the post-10,000-year period, net infiltration and precipitation are not used because the percolation rates are prescribed in NRC Proposed Rule 10 CFR 63.342(c)(2) [DIRS 178394].

In the case of the first metric, net infiltration is the same for the two demonstration modeling cases because the barrier function of surficial soils is independent of the repository conditions. In contrast, the drift seepage (i.e., flow of liquid water into a drift per unit of time per unit area) and seepage fractions (i.e., ratio of WPs experiencing seepage to all WPs in a percolation subregion) are direct functions of hydrologic, thermal, drift degradation, and other repository conditions that depend on modeling cases; thus, these two metrics will have different values for the combined Nominal/Early Failure and Seismic GM Modeling Cases.

**Basis for Net Infiltration Metric**—To ensure a defensible basis for estimates of net infiltration (i.e., water flux across the soil/bed rock interface), a technical work plan (BSC 2006 [DIRS 177492]) was developed for independent evaluations of the available field data, software, and documentation. Those evaluations confirmed that the field data and supporting information used for the TSPA-LA conformed to appropriate quality assurance requirements. In addition, a new infiltration model, Mass Accounting System for Soil Infiltration and Flow (MASSIF) (SNL 2008 [DIRS 182145], Section 6.5.7), was developed and validated in accordance with SCI-PRO-006, *Models*. This new model of infiltration processes was used to develop projections of net infiltration into the bedrock. These projections were compared with published estimates of net infiltration and recharge efficiencies for other Nevada hydrographic areas/subareas (SNL 2008 [DIRS 182145], Section 7.2.1.2[a] and Figure 7.2.1.2-2[a]). The full technical basis for the model and revised assessment of net infiltration at Yucca Mountain is documented in *Simulation of Net Infiltration for Present-Day and Potential Future Climates* (SNL 2008 [DIRS 182145]). The estimates of precipitation and other meteorological data used are documented in *Data Analysis for Infiltration Modeling: Extracted Weather Station Data*
Basis for Drift Seepage Metric—The scientific basis for the projections of three-dimensional UZ flow fields, deep percolation flow, and drift seepage are the end products of more than a decade of studies, including field testing and data collection. The modeling studies have been largely conducted using the well established TOUGH2 family of codes (i.e., TOUGH2 (STN: 10007-1.6-01 [DIRS 161491]), T2R3D (STN: 10006-1.4-00 [DIRS 146654]), and TOUGHREACT (STN: 10396-3.0-00 [DIRS 161256])), which have been subjected to a rigorous validation process using a wide variety of field data from the Yucca Mountain site. More specifically, the UZ flow model and submodels have been tested and corroborated using: (1) water-potential data from the Enhanced Characterization of Repository Block; (2) chloride data from the Exploratory Studies Facility (ESF), Enhanced Characterization of Repository Block, and boreholes; (3) perched water data and pneumatic data from boreholes; (4) carbon-14 data from gas samples; (5) strontium concentrations; and (6) calcite coating (SNL 2007 [DIRS 184614]). Most of the results of the model validation and corroborations are published in refereed scientific journals. The full technical basis for the deep percolation flow models and drift seepage is documented in UZ Flow Models and Submodels (SNL 2007 [DIRS 184614]) and Abstraction of Drift Seepage (SNL 2007 [DIRS 181244]).

Basis for Drift Seepage Fraction Metric—The TSPA-LA Model utilizes an abstraction of UZ flow to determine the percolation flux at the top of the repository horizon. Drift seepage flux is then computed as a function of the local percolation flux (defined as the percolation flux times the flow focusing factor), host rock permeability, and capillary strength (Figure 6.3.3-5 of the parent document). The drift seepage flux calculation is also adjusted to account for drift degradation and a thermal-hydrologic (TH) environment. The seepage fraction is calculated as the ratio of WPs experiencing seepage to all WPs in a percolation subregion; seepage fractions are determined for each WP type. Percolation subregions are described in Section 6.3.2.2.1 of the parent document. The abstractions of drift seepage and seepage fraction are explained in Section 6.3.3 of the parent document; the abstraction of the TH environment is described in Section 6.3.2 of the parent document. The modeling studies and technical basis for these abstractions are documented in Multiscale Thermohydrologic Model (SNL 2007 [DIRS 181383]) and Abstraction of Drift Seepage (SNL 2007 [DIRS 181244]).

8.3.3.1.1[a] Capability of Upper Natural Barrier to Prevent or Reduce Movement of Water to the Waste

Net Infiltration as Percentage of Annual Precipitation—Net infiltration as a percentage of climate dependent annual precipitation is the metric used to provide insights to the effectiveness of the surficial soils and topography to prevent or reduce the rate of water flow into the UZ. In addition, examining the partitioning of precipitation into the various water balance components (i.e., change in water storage in soil, run-off, evapotranspiration, and sublimation) is also useful in explaining the factors controlling net infiltration. The focus here is on the three climate states in the first 10,000 years (Section 6.3.1 of the parent document), namely, the present-day climate defined as occurring for 600 years; monsoon climate defined as occurring from 600 years to 2,000 years; and the glacial-transition which is defined to occur from 2,000 years to 10,000 years.
The following estimates of mean net infiltration rate as a percentage of mean precipitation rate for each climate state are taken from Tables 6.5.7.4-1 through 6.5.7.4-3 of the recent infiltration study (SNL 2008 [DIRS 182145]), namely:

- Present-day climate: \( \bar{I} \sim 8.02\% \) of \( \bar{P} \)
- Monsoon climate: \( \bar{I} \sim 8.69\% \) of \( \bar{P} \)
- Glacial-transition climate: \( \bar{I} \sim 10.38\% \) of \( \bar{P} \)

where \( \bar{I} \) is the mean net infiltration rate as a percentage of \( \bar{P} \), the mean precipitation rate. Ranges of net infiltration for the four infiltration scenarios (defined by the 10th, 30th, 50th, and 90th percentiles of spatially averaged infiltration, see Section 6.3.1 of the parent document) can be summarized as follows. Estimated average present-day net infiltration ranges from less than 3 percent of precipitation for the drier 10th percentile infiltration scenario to about 13 percent of precipitation for the 90th percentile infiltration scenario (SNL 2008 [DIRS 182145], Table 6.5.7.1-3). For the monsoon climate, average net infiltration rate estimates for the 10th to 90th percentile infiltration scenarios range from about 3 percent to 17 percent of precipitation (SNL 2008 [DIRS 182145], Table 6.5.7.2-3). For the glacial-transition climate, the average net infiltration rate estimates for the 10th to 90th percentile infiltration scenarios range from about 5 percent to 16 percent of precipitation (SNL 2008 [DIRS 182145], Table 6.5.7.3-3). Note that the ratios of net infiltration to precipitation presented above are averaged over the entire infiltration model domain, not over the repository footprint area.

Water balance components tabulated in Simulation of Net Infiltration for Present-Day and Potential Future Climates (SNL 2008 [DIRS 182145]) show that the process of evapotranspiration (i.e., transfer of moisture from soil to the atmosphere by evaporation and transpiration from plants) alone accounts for most of the reduction in infiltration into the surficial soils; this reduction ranges from 85 to 88 percent of the mean precipitation rate (SNL 2008 [DIRS 182145], Tables 6.5.7.4-1 through 6.5.7.4-3). The remainder of the reduction is accounted for by the change in storage of moisture in the soil and surface runoff. The infiltration study contains comparisons with published estimates for other Nevada hydrographic areas/subareas (SNL 2008 [DIRS 182145], Section 7.2.1.2[a] and Figure 7.2.1.2-2[a]).

Seepage Rate as Percentage of Local Percolation Rate—Water entering the UZ as net infiltration from precipitation at the land surface affects the overall hydrological and thermal-hydrological (TH) conditions within the Yucca Mountain UZ. Net infiltration is the ultimate source of percolation through the UZ. Water percolating downward through the UZ is the source for seepage into the drifts. Multi-dimensional modeling of water flow in the UZ rock layers suggests that average percolation flux flowing to the repository footprint is within a few percent of the net infiltration rate (SNL 2007 [DIRS 184614], Section 6.1.4). This means that lateral flow in the Paint Brush non-welded (PTn) tuff, flow focusing in faults in the northern part of the repository, and perched water zones collectively have a small effect on reducing the local percolation rate at the top of the repository horizon. Of the water flow (percolation) arriving at the repository horizon, however, only a small portion results in drift seepage. The reduction from percolation to seepage is the result of two natural processes that divert flow around and away from the emplacement drift; these processes (SNL 2007 [DIRS 181244], Section 6.1.4) are referred to as: (1) the vaporization barrier effect during the thermal period, and (2) the capillary
barrier effect after the thermal period. While the vaporization barrier effect persists for a short time relative to the compliance periods, the capillary barrier effect persists through the period of geologic stability.

The surface soil and topography, the surficial bedrock, and the TSw unit will combine to substantially reduce movement of water from the surface of Yucca Mountain into the emplacement drifts. The combination of reduced infiltration into Yucca Mountain, effects of heat during the thermal period, and capillary barrier effects in the TSw unit, results in a seepage flux that will be substantially reduced from the precipitation flux at the surface. The magnitude of this reduction is shown on Figure 8.3-3[a].

The surface soil and topography, the surficial bedrock, and the TSw unit will combine to substantially reduce movement of water from the surface of Yucca Mountain into the emplacement drifts. The combination of reduced infiltration into Yucca Mountain, effects of heat during the thermal period, and capillary barrier effects in the TSw unit, results in a seepage flux that will be substantially reduced from the precipitation flux at the surface. The magnitude of this reduction is shown on Figure 8.3-3[a]. The top figure (a) illustrates the effectiveness of surficial soils and topography in preventing or reducing the rate of water flow into the UZ. The bottom figure (b) illustrates the effectiveness of decay heat and capillary diversion in limiting water movement into the drifts. On Figure 8.3-3a[a], mean spatially-averaged annual precipitation and net infiltration rates are plotted for each of the three climate states in the 10,000-year compliance period. Net infiltration rates are shown to range from approximately 5 percent of precipitation during the present-day climate to over 7 percent of precipitation during the glacial-transition climate. For the post-10,000-year period, the effects of infiltration are implicitly included in the TSPA-LA Model by using the distribution for deep percolation rate as specified in NRC Proposed Rule 10 CFR 63.342(c)(2) (70 FR 53313 [DIRS 178394]), namely, a log-uniform distribution with a range of 13 to 64 mm/yr. The mean value of deep percolation from this distribution, 32 mm/yr, is shown on Figure 8.3-3a[a].

Three mean spatially-averaged drift seepage flux curves are shown on Figure 8.3-3b[a]. The top curve denoted by the dashed line represents a zero-diversion seepage flux that would result if capillary and thermal effects at the drift wall were neglected. This volumetric seepage flux is obtained by applying the average net infiltration flux to the projected area of an intact emplacement drift segment that is 5.1 m long by 5.5 m wide. This zero-diversion seepage flux is compared to the TSPA-calculated seepage fluxes for the two demonstration modeling cases (i.e., the combined Nominal/Early Failure Modeling Case and the Seismic GM Modeling Case) to illustrate the effectiveness of the UZ barrier in limiting the movement of water into the drifts. Note that the average net infiltration flux and, thus, zero-diversion seepage flux used here, is based on a spatial averaging over the entire infiltration model domain. Therefore, the zero-diversion seepage flux is only a representative approximation of the average flux that would occur within the repository footprint.

In contrast, the TSPA-calculated seepage fluxes are based on the percolation flux within the repository footprint. The nominal seepage flux curve shows that seepage varies in the early part of the thermal period when temperatures above 100°C are achieved; as temperatures gradually decrease to lower values, seepage fluxes into the drift increase. The estimate shows that for the 10,000-year compliance period, on average, 2 to 11 percent of the zero-diversion seepage flux occurs as seepage into the drifts. The mean seepage flux for the post-10,000-year period is about 0.095 m³/yr or about 11 percent of the zero-diversion seepage flux.

The seepage curve for the Seismic GM Modeling Case is discussed next. For the first 10,000 years, the mean seepage flux curve is almost identical to the mean curve for the combined Nominal/Early Failure Modeling Case. This similarity occurs because seismic events of sufficient magnitude that cause drift degradation are unlikely to occur in this time period. The
likelihood of seismic events is described by the mean seismic hazard curve (Figure 6.6-6 of the parent document), which shows that exceedance frequencies on the order of $10^{-4}$ yr$^{-1}$ correspond to relatively small amplitude vibratory ground motions that are unlikely to result in rockfall (Section 6.6.1.2.1 of the parent document). The drift degradation aspect is based on the simulations of rockfall resulting from seismic ground motion events, which are shown on Figure 7.3.2-19 of the parent document. This figure indicates that for most realizations, drift degradation, quantified in terms of mean rubble volume per meter of drift length (i.e., seismic induced rockfall), is less than 5 m$^3$/m and 0.5 m$^3$/m for both the lithophysal and nonlithophysal rock zones, respectively, for the first 10,000 years. The lithophysal rock zones encompass approximately 80 to 85 percent of the emplacement drifts in the repository (Section 6.6.1.2.2). As described in Section 6.3.3.1.3, a mean rubble volume of less than or equal to the 5 m$^3$/m of drift length for lithophysal rock zone or 0.5 m$^3$/m for nonlithophysal rock zone indicates that the emplacement drifts are essentially intact and, thus, the seepage rates are determined by nominal flow processes in the repository horizon. Consequently, the values of the seepage rate metric are about the same as those for the combined Nominal/Early Failure Modeling Case.

For the post-10,000-year time period, the Seismic GM Modeling Case seepage rates on Figure 8.3-3b[a] are significantly different from the seepage rates for the combined Nominal/Early Failure Modeling Case. These differences are due to a greater degree of drift degradation and, at late times, to drift collapse in lithophysal rock (i.e., lithophysal rubble volume 60 m$^3$/m or greater). In nonlithophysal rock, once rockfall has accumulated to an amount of 0.5 m$^3$/m, capillary diversion is no longer considered, and the seepage rate is set to the percolation rate in the TSPA-LA Model. The spatially averaged mean seepage rates for the Seismic GM Modeling Case increase with time and are larger than those for the combined Nominal/Early Failure Modeling Case. The mean drift seepage rates for the Seismic GM Modeling Case range from 0.109 m$^3$/yr just after 10,000 years to about 0.434 m$^3$/yr at 1,000,000 years. For these same two times, the seepage rates, as a percentage of the mean zero diversion seepage rate calculated using the NRC prescribed local percolation rate, are about 12 percent and 48 percent, respectively. Although the effectiveness of capillary diversion is reduced from that of the combined Nominal/Early Failure Modeling Case, it is still substantial in the Seismic GM Modeling Case.

**Seepage Fractions for Percolation Subregions**—Drift seepage rates are expected to vary spatially over the length of the emplacement drifts. This means that emplacement drifts can exhibit both seeping and non-seeping environments (Section 6.3.3.1.1). In the TSPA-LA Model, this spatial variability is quantified by the seepage fraction. The seepage fraction is the ratio of the number of WPs experiencing seepage to the total WPs in a percolation subregion; separate values are computed for CDSP and CSNF WPs. Distributions of seepage fraction have been computed for each climate and for the five percolation subregions that represent the repository footprint. The calculations were performed using a three-dimensional flow model (BSC 2004 [DIRS 167652]) and a probabilistic approach (SNL 2007 [DIRS 181244], Section 6.5); implementation of the abstraction in the TSPA-LA Model is described in Section 6.3.3.2.2. Seepage fractions for all five percolation regions are provided in Tables 8.3-2[a] through Table 8.3-4[a]. Unlike seepage rates, which vary with time, seepage fractions are constant values that are based on the percolation flux at the end of the simulation period (either 10,000 years or one million years).
For the combined Nominal/Early Failure Modeling Case, statistics for the distributions of the seepage fraction are tabulated in Table 8.3-2[a] for glacial-transition climate (2,000 to 10,000 years) and in Table 8.3-3[a] for post-10,000-year deep percolation rates. The statistics consist of mean and 5th and 95th percentiles for each WP type (i.e., CDSP and CSNF). As can be noted from Table 8.3-3[a], for the post-10,000 year period the mean seepage fraction in percolation subregion 3 is \( \sim 0.44 \) for the CDSP and CSNF WP locations. Percolation subregion 5, which represents about 5 percent of the repository footprint, has the highest mean seepage fraction of \( \sim 0.49 \) for both CDSP and CSNF WPs. Averaging over the entire repository footprint, the mean seepage fractions for both CDSP and CSNF WPs are \( \sim 0.4 \); this indicates that, on average, in the post-10,000-year period, about 60 percent of the emplacement locations in the repository have non-seeping environments for the combined Nominal/Early Failure Modeling Case.

For the Seismic GM Modeling Case, the seepage fraction statistics are tabulated in Table 8.3-4[a] for glacial-transition climate (2,000 to 10,000 years) and Table 8.3-5[a] for post-10,000 year deep percolation rates. As can be noted from Table 8.3-5[a], for the post-10,000 year period the mean seepage fraction in percolation subregion 3 is \( \sim 0.72 \) for both CDSP and CSNF WPs. Percolation subregion 5, which represents about 5 percent of the repository footprint, has the highest mean seepage fractions of \( \sim 0.75 \) for both the CDSP and CSNF WP locations. The mean seepage fraction for the overall repository footprint is \( \sim 0.7 \) for both CDSP and CSNF WP locations. This indicates that for the post-10,000-year period, about 30 percent of the emplacement locations in the repository are in non-seeping environments for the Seismic GM Modeling Case. It is important to note that the calculations of mean seepage fractions for the Seismic GM Modeling Case account for effects of drift degradation and collapse, which reduce the flow diversion by the capillary barrier (BSC 2004 [DIRS 167652], Section 6.6.3). This is the reason that the seepage fractions are higher than those for the combined Nominal/Early Failure Modeling Case.

**8.3.3.2[a] Engineered Barrier System**

The basic role of the EBS is to provide long-term containment and to prevent and delay the release of radionuclides into the lower natural barrier. The EBS achieves this design intent by ensuring two important barrier functions: (1) preventing or substantially reducing the amount of seepage water and drift wall condensation that contacts the waste, and (2) preventing or substantially reducing the rate of release of radionuclides from the EBS to the lower natural barrier. The first barrier function is provided by the emplacement drift, DS, and WP OCB (Figure 6.3.6-4), whereas the second function is provided by the various waste forms, the WP OCB, corrosion products from WP internals, and the crushed tuff in the invert. The TSPA-LA Model was used to demonstrate EBS barrier capability; as described in Section 6.1.1, excluded features, events and processes are not considered in this demonstration.

**Drip Shield and Waste Package Performance Metrics**—To provide a basis for assessing the capability of the EBS to achieve the first barrier function, projections for three barrier capability metrics were developed for the DSs and WPs. The first metric is the DS failure time profile, which is quantified in terms of a cumulative probability distribution function (CDF) for failure time of the DS plates (Titanium Grade 7). DS failure is defined as a hole or opening through the 15-mm thick DS plate; breach of the plate by SCC cracks is not considered as a DS failure
because a crack-damaged DS will still prevent seepage water from contacting the underlying WP. The second capability metric is the WP breach time profile, which is defined as a penetration of the OCB (Alloy 22 [UNS N06022]) by either cracks or patch openings. In the combined Nominal/Early Failure Modeling Case, WP breaches include crack breaches due to SCC of the closure lid welds and patch breaches of the WP OCB due to general corrosion penetrations. In the Seismic GM Modeling Case, crack breaches include seismically-induced SCC of the WP OCB as well as SCC of the closure lid welds; patch breaches include seismically-induced rupture and puncture, in addition to general corrosion penetrations. In addition, a third metric, the capability of the EBS system to retain radionuclides, addresses the performance of the EBS as a whole.

Insights to potential WP breach modes were developed by examining the breach characteristics underlying these metrics for each of the two demonstration modeling cases. For the combined Nominal/Early Failure Modeling Case, the following two WP breach characteristics (Section 6.3.5) were calculated and are presented:

1. Fraction of WPs breached by general corrosion (i.e., patch penetration) as a function of time
2. Fraction of WPs breached by cracks (i.e., nominal process SCC in closure welds) as a function of time.

The following three WP breach characteristics (Section 6.6 of the parent document) for the Seismic GM Modeling Case are presented and discussed:

1. Fraction of WPs breached by nominal and seismic ground motion processes as a function of time
2. Fraction of WP surface area breached by nominal and seismic ground-motion induced SCC cracks per breached WP as a function of time
3. Fraction of WP surface area breached by patches resulting from general corrosion and seismic induced puncture and rupture failure mechanisms per breached WP as a function of time.

In the following discussion, WP performance is generally presented in terms of mean barrier capability metrics and breach characteristics. To illustrate uncertainty in these metrics and characteristics, quantiles (median, 5th, and 95th percentiles) are also shown. It is important to note that the TSPA-LA Model computes WP degradation metrics and breach characteristics for each of five percolation subregions that represent the repository footprint. The graphical results presented in the following sections for the WPs were computed as a weighted average combining all of the five percolation regions to arrive at a representation for the entire repository.

An assessment of the EBS capability as a whole to achieve the second barrier function was developed based on probabilistic projections of mean radionuclide activity (in curies) released from the EBS as a function of time. This barrier capability metric is calculated using the inventory balance equation:
\[
\overline{R}_{EBS,k}(\tau | \mathbf{e}) = \overline{A}_{T,k}(\tau | \mathbf{e}) - (\overline{A}_{WP,k}(\tau | \mathbf{e}) + \overline{A}_{I,k}(\tau | \mathbf{e}))
\]  
(Eq. 8.3.3-1[a])

where \( \overline{R}_{EBS,k}(\tau | \mathbf{e}) \) is the expected (average over aleatory uncertainty) activity (Ci) of radionuclide \( k \) released from the EBS; \( \overline{A}_{T,k}(\tau | \mathbf{e}) \) is the expected activity (Ci) of radionuclide \( k \) in the inventory disposed in the geologic repository (initial inventory decayed through time); \( \overline{A}_{WP,k}(\tau | \mathbf{e}) \) is the expected activity (Ci) of radionuclide \( k \) retained in the WPs (including the activity still in undegraded waste forms); and \( \overline{A}_{I,k}(\tau | \mathbf{e}) \) is the expected activity (Ci) of radionuclide \( k \) retained in the invert. The term \( \tau \) is time, and \( \mathbf{e} \) is the set of epistemically uncertain parameters, which are sampled in the Monte Carlo simulation (output DTN: MO0701PLOTSFIG.000 [DIRS 185207], file: Calculation of expected activity Seismic GMD 10K.doc). The activity quantities, \( \overline{A}_{T,k}(\tau | \mathbf{e}) \), \( \overline{A}_{WP,k}(\tau | \mathbf{e}) \), and \( \overline{A}_{I,k}(\tau | \mathbf{e}) \), are obtained from the Monte Carlo simulation performed with the TSPA-LA Model.

**Basis for Engineered Barrier System Barrier Capability Projections**—The conceptual models and mathematical basis for DS and WP degradation can be found in Section 6.3.5. An important aspect to note is that the DS degradation abstraction does not implement spatial variability for general corrosion rates. This means that all DSs in the repository fail in unison at the failure time determined by the general corrosion model and the DS fragility abstraction (Section 6.6.1.2.2.1 of the parent document). The uncertain parameters for DS general corrosion are derived from laboratory data for general corrosion of the Titanium Grade 7 samples and are documented in *General Corrosion and Localized Corrosion of the Drip Shield* (SNL 2007 [DIRS 180778]). Similarly, the experimental basis for the WP degradation models and parameters can be found in *General Corrosion and Localized Corrosion of Waste Package Outer Barrier* (SNL 2007 [DIRS 178519]) and *Stress Corrosion Cracking of Waste Package Outer Barrier and Drip Shield Materials* (SNL 2007 [DIRS 181953]).

Probabilistic projections for DS failure and WP breach time profiles were developed to provide insight into barrier capability (output DTN: MO0801TSPAWPDS.000 [DIRS 185077]). These projections used an optimized version of the TSPA-LA Model v5.005 that excludes all transport calculations to efficiently calculate DS and WP failure under nominal and seismic conditions for the purpose of presenting projections of DS and WP performance. The optimized version of the TSPA-LA Model uses the same Monte Carlo simulation approach as the full TSPA-LA Model, which incorporates aleatory and epistemic uncertainties by means of two separate computational loops:

1. An outer calculation loop that samples values from probability distributions for parameters with epistemic uncertainty using the Latin hypercube sampling technique (Helton and Davis 2002 [DIRS 163475])

2. An inner loop that samples, for each epistemic set, values from probability distributions of parameters describing aleatory uncertainty (i.e., randomness) in the occurrence of events.
The optimized version of the TSPA-LA Model uses the same samples for aleatory and epistemic uncertainty as are used to produce the TSPA-LA Model results shown in Section 8.1[a] and Section 8.2[a].

For the combined Nominal/Early Failure Modeling Case, the probabilistic analysis of DS capability (output DTN: MO0801TSPAWPDS.000 [DIRS 185077], file: v5.005_NC_000300.gsm) included general corrosion of the DS plates; other DS corrosion mechanisms such as localized corrosion have been screened out (Section 6.3.5.1 and Table 6.3.5-1). As described in Section 6.3.5, the degradation of the topside of the DS plate is based on a corrosion rate model for an aggressive water chemistry environment (i.e., elevated fluoride concentration), whereas the underside surface degradation is based on a corrosion rate model for water chemistry representative of a benign environment. For the WPs, WAPDEG was applied to analyze WP degradation, taking into account the following processes: general corrosion, microbiologically influenced corrosion, and SCC in the closure-lid weld region. Localized corrosion of the WPs was analyzed with a standalone model using GoldSim (external to WAPDEG) and was shown not to impact the combined Nominal/Early Failure Modeling Case or the Seismic GM Modeling Case (Section 6.3.5.2.3).

As described in Section 6.4 of the parent document, a DS or WP early failure is characterized as a through wall penetration of a WP or DS caused by manufacturing or handling-induced defects that occurs prior to or at the time of repository closure. In the case of the early DS failure, the penetration of the DS plate is assumed to represent complete failure of the DS. In addition, if an early-failed DS is located in a seeping environment, it is assumed that the underlying WP is completely degraded by localized corrosion processes. In the case of early WP failure, it is assumed that the entire surface of the WP is completely degraded. The probabilities of early failure of a randomly selected DS or WP are sampled from lognormal distributions (Sections 6.4.1.3 and 6.4.2.3).

For the Seismic GM Modeling Case (Section 6.6), analysis of the seismic impacts to the DS and WP degradation was performed by first applying WAPDEG to simulate the nominal corrosion processes, then transferring the calculation results to GoldSim to evaluate damage and breaches caused by vibratory ground motion. Details of the associated model implementation are discussed in Sections 6.6.1.3 and 6.6.2.3 of the parent document.

**8.3.3.2.1[a] Engineered Barrier System Capability to Prevent or Reduce Movement of Water to the Waste**

The DSs serve as the first engineered feature that prevents seepage and drift wall condensation water from contacting the WPs and thereby the waste forms. The DSs would maintain this barrier function until the 15-mm thick DS plates are fully penetrated by general corrosion or ruptured as a result of seismic events. As explained in Section 6.3.5.1.1, Table 6.3.5-1, localized corrosion of DS plates has been screened out (DTN: MO0706SFAEPLA.001_R1 [DIRS 185200], FEP 2.1.03.03.0B). The DS capability to achieve the first barrier function is demonstrated considering both nominal general corrosion of the plate (topside and underside surfaces) and seismic induced loading (dynamic and static) causing plate failure (rupture).
The WPs serve as the second feature that prevents water from contacting the waste forms. The WP barrier capability is demonstrated by considering breaches attributed to:

- Nominal corrosion degradation conditions: SCC of the closure-lid weld region (Figure 6.3.5-7) and general corrosion of the WP OCB.

- Seismic ground motion conditions: seismic-induced SCC, rupture, and puncture of the WP OCB, combined with breaches due to nominal corrosion processes. The seismic-induced SCC of the WP OCB is attributed to a local residual stress exceeding a residual tensile stress threshold for SCC initiation and is conceptualized as a tightly spaced network of stress corrosion cracks (Section 6.6.1.1.2). Note that the DS and WP capability analysis results for these conditions also include degradation by the nominal corrosion mechanisms.

It is important to note that the process of liquid water flow through the stress corrosion cracks in the WP OCB has been screened out (Section 6.3.6.1 and DTN: MO0706SPAFePLA.001_R1 [DIRS 185200], FEP 2.1.03.10.0A). Consequently, liquid seepage water would not contact the waste form until a patch penetration develops in the WP OCB. The significance of SCC to EBS capability to achieve the second barrier function is addressed in Section 8.3.3.2.2[a].

The following sections present results for each performance metric for the EBS capability to prevent or reduce movement of water to the waste, as well as characteristics for breaches of WPs, namely:

- DS failure time for nominal conditions
- WP breach time for nominal conditions
- WP breach characteristics for nominal conditions
- DS failure time for seismic ground motion conditions
- WP breach time for seismic ground motion conditions
- WP breach characteristics for seismic ground motion conditions.

**Drip Shield Failure Time Profile for Nominal Conditions**—A failure time profile for the DSs was developed via a probabilistic projection of the general corrosion degradation of the DS plates as a function of time. For this performance metric, DS failure under nominal conditions is defined as complete penetration of the DS plate by general corrosion (Section 6.3.5). Degradation of the DS framework is also considered and used in the seismic damage abstraction. However, analyses indicate that DS framework failure does not alter the capability of the DS plates to deflect seepage away from the WPs (Section 6.6.1.2.2.1).

Because spatial variability in DS general corrosion rates is not represented in the TSPA-LA Model (Section 6.3.5.1.2), the distribution of the DS failure times simplifies to a single CDF, representing the uncertainty in the failure time for all the DSs in the repository. To calculate the CDF for DS plate failure times, the WAPDEG software was run with a total of 300 epistemic realizations. Each realization is based on one sampled general corrosion rate for each of the topside and underside plate surfaces from their respective distribution (Table 6.3.5-3).
The epistemic uncertainty in the general corrosion rates for the topside and underside surfaces are represented by CDFs (SNL 2007 [DIRS 180778], Section 8.1[a]) developed from laboratory data. The corrosion rate CDF for the topside is for aggressive corrosion conditions, while the CDF for the underside is for benign corrosion conditions. The distribution of DS plate failure times is shown on Figure 8.3-4[a]. Uncertainty in failure time is dominated by the uncertainty in the general corrosion rate for the topside (Appendix K, Section K4.2, of the parent document); this is because the corrosion rate on the topside of the DS is much greater than that on the underside. The CDF for DS plate failure times has a median value of approximately 290,000 years. A histogram of this failure time profile is presented in Section 8.1[a] (Figure 8.1-4[a]), which shows the majority of the Monte Carlo realizations with DS plate failure times ranging from 270,000 to 340,000 years.

**Waste Package Breach Time Profiles for Nominal Conditions**—Breach time profiles for the WPs for the Nominal Modeling Case were developed via a probabilistic projection of the breaches consisting of cracks in the closure lid-weld region of the WP OCB (Section 6.3.5.1.1) and corrosion patch penetrations of the WP OCB (Section 6.3.5.1.1). Projections were made for both the CDSP and CSNF WPs over the entire repository. To calculate the breach time profile as a function of time, a total of 300 epistemic realizations were run. Spatial variability in the degradation processes is modeled by the WAPDEG software. Temporal variability in the degradation processes is represented by the temperature-dependent general corrosion rate of the WP OCB (Section 6.3.5.1.2). The breach time profiles for both types of WPs are summarized by the fraction of WPs breached as a function of time, shown on Figure 8.3-5[a]; these plots show curves corresponding to the mean, median, and 5th and 95th percentiles.

Comparing the plots on Figures 8.3-5[a] and 8.3-5[b], it is evident that the CDSP and CSNF WP breach time profiles for nominal conditions are very similar. This similarity is explained by the fact that the two WP types have common design characteristics (e.g., OCB material [Alloy 22], OCB thickness [25 mm], and closure-lid weld stress mitigation method [i.e., low plasticity burnishing] for the closure weld surface (Section 6.3.5.1)). A small difference in breach-time profiles is expected because the two WP types have different temperature histories (i.e., CSNF WPs have higher thermal output and therefore a hotter outer surface than the CDSP WPs (SNL 2007 [DIRS 181383], Figure 6.3-82[a])), which affects general corrosion rates. In addition, because the CSNF and CDSP WPs have different nominal diameters and therefore different closure-lid weld volumes, different values for the associated SCC-model parameters for the closure-lid weld region are expected to introduce small differences in the SCC crack breach time profiles for the WPs. Based on the 95th percentile curves, CDSP and CSNF WPs breaches are likely to begin occurring after approximately 170,000 years. The mean curves for both WP types show that approximately 54 percent of the WPs could be breached at one million years as a result of SCC crack penetration and general corrosion patch penetration.

**Waste Package Breach Characteristics for Nominal Conditions**—To better understand the degree of degradation of the WPs under nominal corrosion conditions in the repository, the model results were analyzed to quantify the fraction of CDSP and CSNF WPs: (1) breached by SCC as a function of time, and (2) breached by general corrosion patches as a function of time. Under nominal conditions, SCC occurs in the closure-lid weld region of the WP OCB and general corrosion occurs over the entire WP OCB surface, including the closure weld region. Additional breach characteristics were calculated to estimate the expected fraction of WP surface
area breached by crack and patch penetrations as a function of time, per breached WP. Because the breach profiles for CDSP and CSNF WPs are very similar, only the nominal corrosion breach characteristics for the CSNF WP are discussed herein. Figure 8.3-6[a] shows the projected fraction of CSNF WPs breached as a function of time, which illustrates the initiation and timing of the two breach modes.

From the 95th percentile curve on Figure 8.3-6a[a], breach of CSNF WPs by SCC becomes more likely to occur after approximately 170,000 years. At the end of the one-million-year period, the mean fraction of the WPs with at least one SCC crack breach is 0.54, or 54 percent of the CSNF WPs in the repository. This result also means that almost half of the CSNF WPs would not be breached by SCC cracks within one million years. Comparing these results with those for the first breach-time profile of CSNF WPs (Figure 8.3-5[a]) confirms that the initial breach of the WPs would be by SCC. It is important to reiterate that the cracks induced by SCC are highly tortuous, tight hairline cracks (SNL 2007 [DIRS 181953], Section 6.7.1). Because of these typical tight hairline crack properties, plus sealing the cracks by corrosion products and mineral precipitates, no water in a liquid phase would flow into the WPs and contact the waste forms; however, diffusion of water vapor through cracks and into the WPs is accounted for in the TSPA-LA Model.

Based on the 95th percentile curve on Figure 8.3-6b[a], the CSNF WP is unlikely to be breached by a general corrosion patch penetration before about 560,000 years. By one million years, the mean fraction of the CSNF WPs with at least one patch breach is approximately 0.09 or 9 percent. This suggests that about 90 percent of the CSNF WPs in the repository would not exhibit general corrosion patch penetrations before one million years. It is important to note that the curves for the 5th percentile and median are absent from Figure 8.3-6b[a] due to the large number of realizations with no patch penetration by general corrosion (i.e., zero occurrences) within one million years.

**Drip Shield Failure Time Profile for Seismic Ground Motion Conditions**—The mechanical strength properties of the DS plates (i.e., Titanium Grade 7) and framework (i.e., Titanium Grade 29) were specifically selected to perform their barrier function in the seismic environment of the Yucca Mountain site. However, over the very long time periods specified in the NRC regulation, the combination of dynamic loads induced by vibratory ground motion, static loads associated with drift degradation and rubble accumulation, and plate thinning due to general corrosion would ultimately cause failures of the DSs. As outlined in Section 6.6.1.1.2 of the parent document, vibratory ground motion can cause DS plates to:

1. Rupture when the local strain exceeds the ultimate tensile strain
2. Degrade by induced high residual tensile stress resulting in SCC breach.

DS plate failure by large rock block impact in the nonlithophysal zones has been screened out based on low consequence (Section 6.6.1.2.2.1 and DTN: MO0706SPAFEPLA.001_R1 [DIRS 185200], FEP 1.2.03.02.0B). In the lithophysal units, the accumulation of rubble from multiple seismic events and the dynamic motion during a seismic event can generate SCC damaged areas on DSs. Because advective flow through stress corrosion cracks in DSs sealed by corrosion products and mineral precipitates has been screened out (DTN: MO0706SPAFEPLA.001_R1 [DIRS 185200], FEP 2.1.03.10.0B), the DS damage due to SCC is
not included in the TSPA-LA Model. In addition to being affected by dynamic and static loads, the DS plates are subjected to degradation by general corrosion. Failure of the DS framework occurs as a result of buckling that would be caused by the combined processes of general corrosion of the framework and seismic-induced loads. Buckling of the framework does not alter the capability of the DS plates to divert seepage away from the WPs (Section 6.6.1.2.2.1); however, the framework failure does affect the susceptibility of the underlying WPs to seismic damage from subsequent ground motion events because it inhibits the free motion of the underlying WPs and then of the emplacement pallets.

The DS plate failure time profile for seismic ground motion conditions was computed by the TSPA-LA Model using a total of 300 epistemic realizations, with 30 aleatory realizations to represent random sequences of future seismic events for each epistemic realization. The epistemic and aleatory sampled elements are the same as those used to generate results for the Seismic GM Modeling Case for post-10,000 years (Section 8.2.4.1[a]). The failure (rupture) time profile for the DS plates is described by the CDFs presented on Figure 8.3-7[a]. The plot on Figure 8.3-7[a] shows three types of curves: (1) the set of 300 CDFs constructed from the 30 aleatory realizations for each of the 300 epistemic realizations, (2) the best estimate CDF for DS failure time, and (3) the expected (averaged over epistemic uncertainty) CDF of DS plate failure times. Figure 8.3-7[b] shows the CDF of expected (averaged over aleatory uncertainty) DS plate failure times, along with the 95 percent confidence interval.

As used here, the best estimate CDF is defined as an unbiased estimate of the CDF based on all the simulation outcomes for the DS plate failure times. Based on this definition, the CDF is constructed directly from all 9,000 realizations (300 epistemic and 30 aleatory) simulated by the TSPA-LA Model; this CDF includes both aleatory uncertainty (randomness) and epistemic uncertainty (uncertainty in knowledge). The best estimate CDF on Figure 8.3-7[a] has the following statistics: (1) median of \( \sim 255,000 \) years, (2) 5th percentile of 191,000 years, and (3) 95th percentile of \( \sim 280,000 \) years. The long leading tail of the CDF indicates that very few DS plate failures occur before 100,000 years. In fact, only about 50 out of the 9,000 realizations exhibit DS plate failures before 100,000 years; this means that there is approximately a 0.55 percent chance of DS plate failure occurring at or before 100,000 years by seismic events. DS plate failures before 100,000 years are the result of low probability high magnitude seismic events. The probability of DS plate failures increases gradually after 100,000 years as thinning of the DS plate progresses by general corrosion. At about 200,000 years, the DS plate is projected to have thinned to about one-third of its original thickness or \( \sim 5 \text{ mm} \) (assuming a mean corrosion rate of \( \sim 51 \text{ nm/yr} \); DTN: SN0704PADSGCMT.001_R2 [DIRS 182122]), making it much more susceptible to failure. From the best estimate CDF, the average probability of DS plate failure on or before 200,000 years is approximately \( 6 \times 10^{-2} \); after about 300,000 years, the probability of the DS plate failures is effectively one.

The set of 300 CDFs on Figure 8.3-7[a] is presented to illustrate the range of uncertainty about the best estimate CDF. Each CDF represents the uncertainty introduced by parameters with aleatory uncertainty (e.g., timing of seismic event) and is conditional on the set of parameter values (e.g., general corrosion rates for topside and underside DS plate surfaces) sampled for the given epistemic realization. The spread among the CDFs gives an estimate of uncertainty in DS plate failures associated with epistemically uncertain parameters. The expected CDF highlights the influence of aleatory uncertainties. The expected CDF, which is computed by averaging over
the epistemic uncertainty, represents what should be on average the randomness in the time of DS plate failure. As can be noted from the plot, it is very close to the best estimate CDF except in the tails of the distribution.

The influence of epistemic uncertainty on DS plate failure times is highlighted by the CDF of expected DS plate failure times, which is shown on Figure 8.3-7b(a). In this case, the CDF was constructed by averaging over the aleatory uncertainty to obtain an expected DS plate failure time for each epistemic realization, then ranking the 300 expected DS plate failure times as a CDF. Recognizing that the accuracy of this CDF is based on only 30 aleatory realizations, the 0.95 confidence interval was computed and plotted on Figure 8.3-7b(a); this confidence interval provides an estimate of the accuracy of each estimate of expected DS plate failure time.

**Waste Package Breach Time Profile for Seismic Ground Motion Conditions**—The mechanical design of the CDSP and CSNF WPs, as well as the corrosion properties of the WP OCB material (i.e., Alloy 22), were specifically selected so the WP would perform its barrier function for a wide range of seismic events and corrosion conditions at the Yucca Mountain site. However, over very long time periods, the combination of dynamic impacts and stress and corrosion processes would ultimately cause breaches in the WP OCB. As outlined in Section 6.6.1.1.2, vibratory ground motion can potentially cause WP damage and breaches of the following types:

1. Breaches of the WP OCB caused by SCC (crack penetration)
2. Rupture of the WP OCB as a result of local strain exceeding the ultimate tensile strain (note that rupture can only occur after the WP internals have degraded following an earlier breach in the OCB)
3. Puncture of the WP OCB as a result of rockfall and sharp corners or edges from degraded WP internals.

With regard to the latter two breach modes, rupture can occur while the DSs are intact; puncture can occur after DS failure. In the Seismic Ground Motion Damage Submodel (Section 6.6.1), it is assumed that the WP internals degrade as structural elements when the WP OCB is breached (typically by SCC); this degradation of internals has the effect of making the WPs more susceptible to seismic damage by subsequent events. The cumulative effects from multiple seismic events are analyzed for the time period of one million years.

The statistics on the expected fraction of breached CSNF WPs as a function of time are shown on Figure 8.3-8a(a) for the nominal and seismic processes combined and for the seismic processes only on Figure 8.3-8b(a). The same statistics for CDSP WPs breached are shown on Figure 8.3-8c(a) and Figure 8.3-8d(a) for the nominal and seismic processes combined, and the seismic processes only, respectively. The mean of the expected fraction of WPs breached under seismic conditions at 200,000 years is projected to be approximately 0.007 for the CSNF WPs (Figure 8.3-8a(a)) and 0.37 for the CDSP WPs (Figure 8.3-8c(a)). In each realization (i.e., combination of epistemic and aleatory sample elements), the fraction of breached WPs, \( F_{b,WP}(\tau | a, e) \), is recorded for each WP type (\( WP \)) within each percolation subregion (\( b \)) as a function of time (\( \tau \)). This fraction is determined by:
where $fN_{b,WP} (\tau | e)$ is the fraction of WPs of type $WP$ within percolation subregion $b$ failed by nominal corrosion processes, and $fS_{b,WP} (\tau | a, e)$ is the fraction failed due to seismic events. Because a seismic event affects all WPs within a percolation subregion, $fS_{b,WP} (\tau | a, e)$ can only have the values 0 or 1. The expected fraction of breached WPs, $\overline{F}_{b,WP} (\tau | e)$, is estimated for each epistemic sample element as the average of $F_{b,WP} (\tau | a, e)$ over the aleatory sample elements. Thus, before any seismic damage occurs, the expected fraction of breached WPs is equal to the fraction of WPs with nominal corrosion damage. However, in the absence of nominal corrosion damage, $\overline{F}_{b,WP} (\tau | e)$ can be viewed as an estimate of the probability that seismic damage has occurred.

At early times before about 200,000 years, breaches of the WPs are primarily due to seismic processes only. Therefore, the expected fraction can be interpreted as a probability that a damaging seismic event has occurred. As shown on Figure 8.3-8b[a], the 95th percentile curve transitions from an expected fraction of 0 to $3.3 \times 10^{-2}$ (which is 1/30) at approximately 61,000 years for CSNF WPs. That is, for 5 percent of the 300 epistemic realizations, the probability of failure due to seismic processes only before 61,000 years is at least 1/30. For 95 percent of the realizations, this probability is lower than 1/30 (note that the probability of 1/30 is linked to the fact that 30 futures are generated to represent aleatory uncertainty). This same level of confidence is reached for CDSP WPs as early as 500 years indicating that CDSP WPs are much less resistant to seismic damage and that damage is likely to occur much earlier.

As can be noted by comparing Figures 8.3-8b[a] and 8.3-8d[a], the CSNF WPs are far less likely to be breached by seismic events than the CDSP WPs. The higher resistance to seismic damage of the CSNF WPs versus the CDSP WPs is explained by the enhanced structural response capability (i.e., damping) contributed by the massive TAD canister in the CSNF WPs (Section 6.6). For both CDSP and CSNF WPs, however, the initial breaches consist of SCC or rupture induced by seismic damage while breaches at very late times are dominated by nominal general corrosion processes. For purposes of comparison, note that for nominal conditions the initial breaches of the CSNF and CDSP WPs are likely to begin occurring, as shown by the 95th percentile curves after approximately 170,000 years (Figure 8.3-5a[a] and Figure 8.3-5b[a]); these breaches are due to the nominal process SCC in the closure-lid weld region.

**Waste Package Breach Characteristics for Seismic Ground Motion Conditions**—To develop a quantitative description of the extent of seismic damage to the CDSP and CSNF WPs, probabilistic projections for two breach characteristics were developed: (1) fraction of the WP OCB surface area breached by cracks, and (2) fraction of WP OCB surface area breached by patches. To provide a comparative basis, the two breach characteristics (fraction of WP OCB surface area breached by cracks and by patches) were also computed for the nominal conditions (i.e., in the absence of disruptive events).

The fraction of surface area breached by SCC cracks (i.e., crack area fraction) per breached (crack or patch) CSNF package is shown on Figure 8.3-9[a]. The probabilistic projection for the
Seismic GM Modeling Case is shown on Figure 8.3-9[a] and for the Nominal Modeling Case on Figure 8.3-9b[a]. Focusing on the plot for the Seismic GM Modeling Case (Figure 8.3-9[a]), the initial slope of the mean curve indicates that the seismic induced SCC would predominately occur within the first 250,000 years. After about 250,000 years, the slope of the mean curve is much smaller, due to a significant reduction in the probability of further seismic damage. This decrease in the probability of further seismic damage is attributed to the failure of DS plates from seismic induced drift degradation, which progressively fills the emplacement drift with rubble. The accumulation of rubble around the WPs after DS failure, in turn, reduces the probability of damage by dynamic impacts (e.g., WP to pallet impacts).

In terms of the mean crack-breach characteristic for seismic conditions, the peak mean crack-area fraction for the CSNF WP occurs at one million years and is approximately $4.3 \times 10^{-5}$. In contrast, the peak mean crack-area fraction for nominal conditions at one million years from Figure 8.3-9b[a] is $6.5 \times 10^{-6}$. The slope of the mean curve on Figure 8.3-9b[a] indicates a steady but gradual progression of additional crack breaches in the closure-lid weld region of the WP OCB. In the closure-weld region, additional SCC cracks can initiate over time as general corrosion removes the stress-mitigated layer of the OCB (SNL 2007 [DIRS 181953], Section 8.4.2.1).

The average crack-breach area fraction per breached WP for the CDSP WPs is presented on Figure 8.3-10[a]. The probabilistic projection for the Seismic GM Modeling Case is shown on Figure 8.3-10a[a] and for the Nominal Modeling Case on Figure 8.3-10b[a]. The mean curve for the Seismic GM Modeling Case shows a very rapid rise in the crack-breach area fraction in the first 50,000 years, then gradually transitions to a near horizontal line after about 250,000 years. The near horizontal line again reflects a sharp decrease in the probability of further seismic damage. The timing of this decrease corresponds to the time frame when the DS plates fail (Figure 8.3-7[a]) and the emplacement drifts are being filled by rubble. The peak mean crack-breach area fraction estimated from Figure 8.3-10a[a] occurs at one million years and is approximately $2.1 \times 10^{-4}$. This estimate of a CDSP WP crack-breach open area is almost five times greater than that for a CSNF WP. The greater crack-breach open area for CDSP WPs reflects a greater accumulation of seismic damage, due to the lower resistance to seismic damage for the CDSP WPs (Section 6.6.1.1.2). Focusing on the peak mean crack-breach area fraction for nominal conditions (Figure 8.3-10b[a]), the largest mean value is $7.1 \times 10^{-6}$.

The average fraction of surface area breached by patches (i.e., patch area fraction) per breached (crack or patch) CSNF WP is shown on Figure 8.3-11[a] for the Seismic GM Modeling Case and the Nominal Modeling Case. It is important to clarify that patch breaches in the Seismic GM Modeling Case (Figure 8.3-11a[a]) include general corrosion penetrations, ruptures, and punctures of the WP OCB, whereas the patch breaches in the Nominal Modeling Case (Figure 8.3-11b[a]) include only general corrosion penetrations. Comparison of the mean curves for breaches by cracks (Figure 8.3-9[a]) and by patches (Figure 8.3-11[a]), shows that breaches by cracks are more likely to occur than patch breaches. The 5th percentile and median are absent from Figure 8.3-11[a] because of the large number of realizations with no patch breaches.

As can be noted on Figure 8.3-11a[a], the mean curve for the CSNF WP OCB average patch-breach area fraction begins abruptly at approximately 240,000 years. This abrupt increase results from the first occurrence of rupture or puncture in the Seismic GM Modeling Case. Due
to the low probability of seismic events that cause crack damage to CSNF WPs (Section 7.3.2.6.1.3.7 of the parent document), which is a prerequisite for rupture of CSNF WP, as well as the low probability of seismic events that induce ruptures or punctures in the WP OCB (Sections 7.3.2.6.1.3.5 and 7.3.2.6.1.3.6 of the parent document), ruptures and punctures occur in only a few realizations. Accordingly, until about 480,000 years, the mean curve remains relatively flat, because it is determined by the few realizations in which ruptures or punctures occur. After 480,000 years, the mean curve ascends gradually, corresponding to an increasing likelihood that general corrosion penetrations have occurred. The timing of the initiation of the general corrosion patch penetrations is consistent with the mean curve for the nominal conditions shown on Figure 8.3-11b[a]. At the end of one million years, the patch-breach area fraction attributed to seismic conditions is about \(2.6 \times 10^{-3}\), whereas for nominal conditions, shown on Figure 8.3-11b[a], it is about \(2.4 \times 10^{-3}\). The similarity between the expected average seismic and nominal patch-breach area fractions indicates that the majority of patch penetrations of the CSNF WP OCB are caused by general corrosion.

Summary statistics for the expected average fraction of CDSP WP surface area breached by patches (i.e., patch area fraction) per breached (crack or patch) CDSP WP are shown on Figure 8.3-12a[a] for the Seismic GM Modeling Case and Figure 8.3-12b[a] for the Nominal Modeling Case. The mean curve for the average patch-breach area fraction for the Seismic GM Modeling Case shows a sharp increase beginning at about 14,000 years and then gradually increases until about 480,000 years. Similar to the results for CSNF WPs, this part of the mean curve is determined by a few realizations in which ruptures and/or punctures occur. Because CDSP WPs are more likely to be damaged by seismic events (Figure 8.3-8c[a]), it is also more likely that CDSP WPs could be ruptured, as evident in the earlier occurrence of patch breaches for CDSP WPs (Figure 8.3-12a[a]) as compared to CSNF WPs (Figure 8.3-11a[a]). At about 480,000 years, general corrosion begins to penetrate the CDSP WP OCB (Figure 8.3-12b[a]). At the end of one million years, the patch-breach area fraction attributed to seismic conditions is about \(4.5 \times 10^{-3}\), whereas for nominal conditions, shown on Figure 8.3-12b[a], it is about \(2.4 \times 10^{-3}\). The larger patch-breach area fraction for CDSP WPs for seismic conditions (as compared to nominal conditions) results because damage to CDSP WPs is relatively likely to occur (Figure 8.3-8d[a]). When SCC occurs, the WP OCB begins to corrode from the inside out, effectively doubling the rate of thinning of the WP OCB (Figure 7.7.1-61[a]), and thus increasing the likelihood of general corrosion patch penetrations before one million years. In addition, the WP internals degrade after seismic damage, and thus the early occurrence of SCC increases the probability that ruptures may occur.

**Summary of the Capability of the Engineered Barrier System to Prevent or Substantially Reduce Water Contacting the Waste**—The capability of the EBS to prevent or limit the movement of water and prevent contact between water and waste depends on the integrity of the DSs and WPs. The performance demonstration for the EBS indicates the DSs remain intact for hundreds of thousands of years and protect the WPs from seepage. Moreover, the majority of WPs remain intact for tens of thousands to hundreds of thousands of years, thus only a fraction of the emplaced waste will be exposed to water during this period.

For the combined Nominal/Early Failure Modeling Case, with early-failed DSs notwithstanding, the performance demonstration projects a distribution of DS plate failure times (Figure 8.3-4[a]) with a median of approximately 290,000 years, with DS plate failure times generally ranging...
from 270,000 to 340,000 years (Figure 8.3-4[a]). For the Seismic GM Modeling Case, the best
estimate distribution of DS failure times (Figure 8.3-7[a]) has a median of about 255,000 years,
with the average probability of DS failure at or before 200,000 years being approximately 0.06.

With regards to WP performance capability, the projected distributions for the mean fraction of
WPs (CDSP and CSNF) breached (Figure 8.3-5[a]) for the Nominal Modeling Case show that at
500,000 years, about 15 percent of WPs would have breaches and at one million years about
54 percent of WPs would be breached. For the Seismic GM Modeling Case, the mean of the
expected fraction of WPs breached at 200,000 years is projected to be approximately 0.007 for
the CSNF WPs (Figure 8.3-8[a]) and 0.37 for the CDSP WPs (Figure 8.3-8c[a]). After 200,000
years, nominal corrosion processes start to dominate the expected fraction of breached WPs for
the Seismic GM Modeling Case. These performance metrics show that the DSs and WPs
together substantially reduce the contact of water with the emplaced waste for hundreds of
thousands of years.

8.3.3.2[a] Engineered Barrier System Capability to Prevent or Reduce the Rate of
Radionuclide Releases

The EBS prevents or substantially reduces the release rate of radionuclides from the waste and
prevents or substantially reduces the rate of movement of radionuclides from the repository to
the accessible environment. The EBS performs these functions by (1) preventing or substantially
reducing the contact of water with the waste, (2) reducing the rate of release due to the slow
alteration of the waste and by limited water flux into the WPs, and (3) reducing the rate of
radionuclide transport from the waste form to the lower natural barrier. This section summarizes
how the different processes contribute to the EBS functions, then presents results demonstrating
the EBS capability to prevent or reduce radionuclide releases for undisturbed (combined
Nominal/Early Failure Modeling Case) and disturbed (Seismic GM Modeling Case) conditions.

WPs can be breached through general corrosion, through seismic damage, or by early failure. In
the latter case, the WPs are assumed to provide no protection from the drift environment starting
at the time of repository closure. After WPs are breached, spent nuclear fuel assemblies and
HLW canisters will be exposed to the drift environment including air, water vapor, and possibly
dripping water. The WP exterior will be subjected to advective seepage flow only if seepage is
dripping at the WP location and the DS fails—possibly due to early failure, seismic ground
motion, or general corrosion of the DS. Seismic-induced rupture or puncture of the WP as well
as general corrosion of the WP can provide pathways for advective flux of water into a breached
WP. Stress corrosion cracks will not permit advective flux of water into the WPs; stress
corrosion cracks will, however, permit the transfer of oxygen and water vapor by diffusion into
the WPs.

Radionuclide transport out of the EBS and into the UZ is dependent on several processes. The
processes discussed below are described in detail in Section 6.3.7 and Section 6.3.8 of the parent
document. After a WP is breached, radionuclides are not available for release and transport until
the following processes have occurred:

- Oxygen and water (liquid water or water vapor) enter a WP enabling degradation of the
  waste form and formation of a liquid pathway for radionuclide transport. At and above
the boiling point of water in the repository, a liquid pathway is assumed not to exist, and no transport of radionuclides takes place. When only water vapor enters a WP, no transport takes place until a continuous water film is formed on the internal components. This condition occurs when the WP temperature falls below 100ºC and the relative humidity in these WPs reaches 95 percent.

- The fuel cladding or HLW canister degrade and fail. (Note: The barrier capability provided by the intact cladding and canisters is not accounted for in the TSPA-LA Model.)

- The solid waste form degrades. This process provides the rate at which the radionuclides are made available for mobilization and release.

- Radionuclides are mobilized into aqueous solution, aqueous colloidal suspension, or gaseous phase. (Note: Gaseous transport is not included in the TSPA-LA Model because it is not a significant release mode (DTN: MO0706SPAFEPLA.001_R1 [DIRS 185200], FEP 2.1.12.06.0A)).

Once water and oxygen are available within a breached WP, corrosion products from degradation of steel internal components would form. In CSNF WPs, these steel components include the fuel basket guides, the TAD canister, and the inner vessel. In CDSP WPs, these steel components include the central support tube and divider assembly and the inner vessel. The TAD canister shield plug (15 in. thick) in CSNF WPs and the inner lid (9 in. thick) in CDSP WPs are not included as contributing to corrosion products available for sorption because the large mass of these components is localized at one end of the WP and therefore should not appreciably affect transport throughout the rest of the WP (SNL 2007 [DIRS 177407], Section 6.5.2.1.1.2 and Section 6.5.2.1.2).

Mobile radionuclides are transported out of the breached WPs and through the EBS to the UZ. Transport out of the breached WPs can occur by advection, when there is a liquid flux through the WPs, and by diffusion through continuous liquid pathways in the WPs, including thin films of adsorbed water. As noted above, a continuous thin film cannot form until the WP temperature falls below 100ºC and the relative humidity interior to the WPs reaches 95 percent. Diffusive transport through WP corrosion products depends on the water saturation, porosity, temperature, and relative humidity in the WPs. In the TSPA-LA Model, it is assumed that temperature and relative humidity in the WPs are equal to the temperature and relative humidity on the WP outer surfaces. The two transport processes (diffusion and advection) are each a function of the type of penetration through the DSs and WPs and the local seepage conditions. Diffusion can occur through stress corrosion cracks or through general corrosion patches in the WP both with and without liquid flux through the WPs. Advection is not considered through stress corrosion cracks or through corrosion patches in the absence of seepage flux.

The corrosion products from the WP internal components have the potential to strongly sorb actinides. The process of radionuclide sorption onto the WP corrosion products and invert ballast material (crushed tuff) is beneficial to performance because this process can retain radionuclides in the EBS and delay release to the UZ. Because the WP corrosion products are in intimate contact or directly in the flow or diffusion path of the radionuclide source inside the
WPs, retardation by corrosion products inside the WPs will occur. However, note that because corrosion products from the structural steel members of the invert are more localized and not necessarily in any flow path from the WPs, sorption onto corrosion products in the invert is not represented in the TSPA-LA Model.

The volume of liquid water that could contact a WP is the sum of the dripping seepage and any condensation that may occur on the drift wall. The volume of dripping seepage is quantified by the abstraction for drift seepage (Section 6.3.3.1 of the parent document); results from this abstraction are discussed in Section 8.3.3.1[a]. The occurrence and volume of condensation are quantified by the Drift Wall Condensation Submodel (Section 6.3.3.2 of the parent report), and results are summarized here.

Within the emplacement drifts, water evaporated from the emplacement drift walls and invert is transported primarily by natural convection from warmer to cooler areas, where it condenses on cooler surfaces such as the drift wall. The rates of evaporation and condensation, as well as the rate of water vapor transport in the emplacement drift, determine the extent of condensation. In-drift condensation is evaluated with the in-drift condensation model (Section 6.3.3.2). This model provides the TSPA-LA Model with both the probability and magnitude of condensation on the drift wall during cool-down. The TSPA-LA Model treats the flow of drift-wall condensation as a source of liquid water to be added to the liquid water entering the drift as seepage. The TSPA-LA Model uses this combined liquid-water source term in the EBS flow and chemical environment calculations.

The in-drift condensation model defines three stages for the occurrence of condensation. Stage 1 is when the drift wall temperature is above the boiling temperature of water at all locations in the drifts. No condensation occurs during Stage 1. Stage 2 is for times between when the first location in a drift drops below the boiling temperature and the last location drops below the boiling temperature. Stage 3 occurs after all WPs (and thus the drift wall) drop below the boiling temperature. Drift-wall condensation results are presented in Tables 8.3-6[a] and 8.3-7[a]. Results in Table 8.3-6[a] show that drift-wall condensation does not occur on CSNF WPs during Stage 2 and that there is a small probability a negligible condensation rate will occur during Stage 3 on a very small fraction of CSNF WPs. Results in Table 8.3-7[a] show that a significant drift-wall condensation rate (approximately 0.5 m³/yr) will occur on all CDSP WPs (probability of one and mean WP fraction of one) during Stage 2 for approximately 1,000 years. For comparison, mean seepage rates at 1,500 years are presented in Table 8.3-8[a]. During Stage 3, which lasts until about 2,000 years after closure, the probability of condensation decreases dramatically and the condensation rates are negligible. Drift-wall condensation ceases after 2,000 years for both CSNF and CDSP WPs.

The impact of condensation water on the barrier capability of CDSP WPs is not significant because DSs do not fail to perform their water diversion function during the time condensation will occur. Thus, in the TSPA-LA Model condensation water is diverted around the CDSP WPs except possibly in the case of a very small number of early DS failures or in the unlikely event of DS failure by fault displacement.
Activity Releases from the Engineered Barrier System for Combined Early Drip Shield Failure, Early Waste Package Failure, and Nominal Processes

The aspects of EBS performance that determine the release of radionuclides as modeled in the TSPA-LA Model for the combined Nominal/Early Failure Modeling Case can be summarized as follows:

- **Nominal processes cause only a single WP breach** (output DTN: MO0710ADTSPAWO.000 [DIRS 183752], LA_v5.005_NC_000300_000.gsm) within the 0- to 10,000-year time interval over all the epistemic samples (Section 8.2.1[a]); WP breach is due to SCC of the closure-lid weld.

- Prior to 170,000 years, radionuclide releases from the EBS are determined by processes related to early DS failure and early WP failure.

- After 170,000 years, radionuclide releases from the EBS are determined primarily by processes related to the failure of WPs from nominal processes.

- DS failure for nominal conditions is defined as a complete breach of the DS plate by general corrosion (Section 6.3.5.1). DS failure times are distributed between 270,000 and 340,000 years (Figure 8.1-4[a]).

- The probability of one or more WP early failures is 0.442 (Section 8.2.2). The expected number of WP early failures is 1.09 (Section 8.2.2).

- The probability of one or more DS early failures is 0.0166 (Section 8.2.2). The expected number of DS early failures is 0.018 (Section 8.2.2).

- Early DS failure is assumed to result in WP failure only if the failed DS is located in a seeping environment; otherwise, there is no WP failure and, hence, no radionuclide release. Water flows into the failed WPs as soon as the WP temperature falls below 100ºC and advective transport occurs immediately (Section 6.4.1.3).

- Early WP failure results in releases of radionuclides only by diffusion prior to DS failure by general corrosion. After DS failure, advective transport can occur if the WP is experiencing dripping conditions.

- By about 340,000 years, all DSs have failed and the number of WPs breached by nominal corrosion processes steadily increases (Section 8.3.3.2[a]). As a result, radionuclide releases due to nominal corrosion processes also tend to increase with time (Figure 8.2-1[a]).

- The TSPA-LA Model represents 11,629 WPs (8,213 CSNF WPs and 3,416 CDSP WPs) (Table 6.3.7-1). In CDSP WPs, HLW contains most of the 99Tc with an average initial inventory of $1.01 \times 10^3$ g (17.2 Ci) per CDSP WP. In contrast, the DSNF component of waste in a CDSP WP contains $1.58 \times 10^2$ g (2.69 Ci) of 99Tc. The amount of 99Tc...
contained in the CSNF waste is substantially greater at $7.55 \times 10^3$ g (130 Ci) per CSNF WP (Section 6.3.7.1, Table 6.3.7-3, and Table 6.3.7-5).

- At 10,000 years, there is a sharp increase in radionuclide releases (Figure 8.2-6a[a]) resulting from the early failure of CSNF WPs. Diffusive transport from early failed CSNF WPs begins between 9,000 years and 14,000 years, whereas diffusive transport from early failed CDSP WPs begins between 500 years and 3,000 years (Section 7.7.1.1[a]). CSNF WPs are hotter than CDSP WPs (SNL 2007 [DIRS 181383], Section 6.3.5, Figure 6.3-53), with the result that releases from CSNF WPs are delayed until both the WP temperature falls below 100ºC and the relative humidity interior to these packages reaches 95 percent, at which time a continuous thin film of adsorbed water required for diffusive radionuclide transport is assumed to be present (Section 6.3.8.1). Because infiltration rates and temperatures vary across the repository footprint, the time at which a continuous thin film of adsorbed water required for diffusive radionuclide transport begins also varies (Section 6.3.8.1).

- Because $^{99}$Tc is assumed to have no solubility limit and to be non-sorbing (Section 6.3.7.5), released technetium moves very rapidly from the EBS to the UZ. The EBS release characteristics of $^{99}$Tc are representative of other highly soluble and non-sorbing radionuclides such as $^{129}$I.

- Because the Waste Package Early Failure Modeling Case is the most dominant case in the first few thousand years for the combined Nominal/Early Failure Modeling Case, $^{239}$Pu is not an important contributor to expected dose over this time period (Figure 8.2-4a[a] and Figure 8.2-6a[a]). Much of the mobilized plutonium sorbs onto stationary corrosion products and its subsequent release depends on the rates of desorption (Section 6.3.8), which results in the slow but steady release of $^{239}$Pu from the WP. (Appendix K of the parent document, Figure K5.3.3-4 and Figure K5.3.5-4 illustrate release of dissolved $^{239}$Pu from the EBS for early failure of one CDSP WP and one CSNF WP, respectively).

- The initial release of $^{239}$Pu from the EBS is primarily from DSNF waste forms, which are conservatively assumed to immediately degrade when a CDSP WP is breached (Section 6.3.7.4.2). The releases of $^{239}$Pu later in the first 10,000 years are primarily from HLW, which degrades relatively slowly over time. Releases of $^{239}$Pu from CSNF WPs are delayed until diffusive transport begins after about 9,000 years (Section 7.7.1.1[a]).

Figure 8.3-13[a] compares the mean total activity of all radionuclides remaining after decay of the initial inventory to the mean total activity of all radionuclides released from the EBS for the combined Nominal/Early Failure Modeling Case for both compliance periods. The plots indicate that under nominal conditions, including early failure of DSs and WPs, only a small fraction (less than $3.9 \times 10^{-7}$) of the activity in the total radionuclide inventory would be released from the EBS in 10,000 years. After one million years, the mean total release would be about 7 percent of the inventory.
Figure 8.3-13[a] indicates that for both the first 10,000 year time period and the post-10,000-year time period, of the 12 radionuclides selected for analysis, $^{99}$Tc is the most significant contributor to mean activity release from the EBS, comprising most of the mean total activity released, even though $^{99}$Tc provides less than one percent of the total activity 1,000 years after closure (Figure 8.3-1a[a]). The contribution for the other radionuclides selected is much less. In the case of plutonium species, the plots on Figure 8.3-13[a] show the activity of radionuclides transported irreversibly sorbed to colloids (designated by the superscript I) and the total activity of the mass in dissolved phase, and reversibly and irreversibly associated with colloids (designated by the superscript T). For americium, only the total activity is plotted because the colloidal phase is small compared to the dissolved phase.

The release of $^{99}$Tc during the first 10,000 years (Figure 8.3-13a[a]) is primarily due to diffusive releases from early failure of WPs and, to a lesser extent, advective releases from early DS failure and concomitant WP failure. Nominal WP degradation processes are not likely to cause WP failures prior to about 170,000 years after closure (Figure 8.3-5[a], as shown by the 95th percentile curve). As a result, average releases from the EBS prior to 170,000 years are determined by processes related to early DS failure and early WP failure. The expected number of early failed WPs is about sixty times greater than the expected number of early failed DSs. In addition, early DS failure is assumed to result in WP failure only if the early failed DS is experiencing seeping conditions. Otherwise, there is no WP failure and, hence, no radionuclide release. Under nominal conditions, approximately 69 percent of the WP locations in the repository have non-seeping conditions (Table 8.3-2[a]); therefore, only about 31 percent of early failed DSs result in failure of the underlying WP. Thus, on average, the number of early failed WPs is about one hundred times greater than the number of failed WPs associated with early-failed DSs. Hence, releases due to early WP failure tend to be substantially greater than releases due to early DS failure.

Furthermore, of those WPs that become breached, radionuclide releases during the first 10,000 years are primarily from the cooler CDSP WPs. As noted above, CSNF WPs are hotter than the CDSP WPs (SNL 2007 [DIRS 181383], Section 6.3.5) with the result that releases from early failed CSNF WPs are delayed until after 9,000 years; whereas releases from early failed CDSP WPs are delayed until after 500 years to allow formation of a continuous thin film of adsorbed water, which is required to initiate diffusive radionuclide transport (Section 6.3.8.1). The initiation of transport from CSNF WPs is illustrated on Figure 8.3-13b[a] by the sharp increases in radionuclide releases at around 10,000 years.

Figure 8.3-1[a] indicates that radionuclides such as $^{90}$Sr, $^{137}$Cs, and $^{241}$Am dominate the total inventory activity at the earliest times. Figure 8.3-13a[a] shows that these radionuclides are released in small amounts from the EBS from early failure of CDSP WPs and/or DSs, and experience only moderate sorption and negligible delay during transport out of the EBS (Section 6.3.7 and Section 6.3.8). Due to the short half-lives of $^{90}$Sr and $^{137}$Cs, these radionuclides are secondary contributors to the mean total activity releases from the EBS for only a few hundred years. Because of the longer half-life of $^{241}$Am, this radionuclide is a secondary contributor to the mean total activity releases until about 2,000 years. A second peak in activity releases of $^{241}$Am occurs just after 10,000 years, caused by releases from early failed CSNF WPs (Figure 8.3-13b[a]).
From about 2,000 to 10,000 years, $^{239}\text{Pu}$ and $^{240}\text{Pu}$ are important contributors to mean total activity released. These two radionuclides dominate the total inventory at 10,000 years with $^{239}\text{Pu}$ and $^{240}\text{Pu}$ contributing 52 percent and 40 percent of the mean total activity, respectively (Figure 8.3-1[a]). $^{239}\text{Pu}$ and $^{242}\text{Pu}$ are less mobile solutes that reversibly sorb to stationary corrosion products in the WPs, which reduces releases from the WPs. On Figure 8.3-13[a], the activity releases of $^{239}\text{Pu}$ and $^{242}\text{Pu}$ are shown as totals (denoted by $^{239}\text{Pu}^T$ and $^{242}\text{Pu}^T$) of the mass in dissolved phase and the mass sorbed on colloids (reversibly and irreversibly); the activity releases of $^{239}\text{Pu}$ and $^{242}\text{Pu}$ irreversibly sorbed on colloids (only) are denoted by $^{239}\text{Pu}^I$ and $^{242}\text{Pu}^I$. The comparison shows that the irreversible colloids contribute only about 1 percent of the mean activity releases of these radionuclides.

The relatively small value of mean total activity release from the EBS after 10,000 years and prior to about 170,000 years (Figure 8.3-13b[a]) is explained by the absence of DS failure (except for early failures) and the limited number of WP failures prior to 170,000 years. As noted above and described in Section 8.3.3.2.1[a], DS failure times range from 270,000 to 340,000 years. In addition, SCC penetrations of the WP closure-lid welds are unlikely to occur before approximately 170,000 years (as shown by the 95th percentile curves on Figure 8.3-9b[a] and Figure 8.3-10b[a]). As SCC penetrations occur, releases from the WPs and EBS increase, as illustrated by the increase in releases of $^{99}\text{Tc}$ at around 170,000 years (Figure 8.3-13b[a]). The amount of activity released from the EBS by moderately soluble and weakly to moderately sorbing radionuclides in the lower natural barrier system (Categories 3 and 4, Section 8.3.1[a]), such as $^{237}\text{Np}$, $^{242}\text{Pu}$, and $^{234}\text{U}$, increases after 200,000 years as well, but substantial increases are not observed until general corrosion failures of WPs begin to occur at about 600,000 years (as shown by the 95th percentile curves; Figures 8.3-11b[a] and 8.3-12b[a]) and subsequent advective releases become significant. However, these releases remain small compared to $^{99}\text{Tc}$ throughout the one-million-year period.

As discussed above, the performance of the EBS in preventing or substantially reducing the rate of radionuclide release to the lower natural barrier is a function of several features and uncertain processes in the EBS. The degree of degradation of the WP is uncertain, spatially variable, and controls the amount and rate of water that may enter the WP and potentially allow degradation of the waste forms. The thermal and chemical environment is also uncertain and spatially variable and affects the degradation rate and characteristics of the waste forms and, more importantly, affects the solubility of the radionuclides in the aqueous phase, as well as the stability of colloids to which radionuclides may be attached. The rate of release is affected by the advective and diffusive transport pathways out of the WPs and through the invert. The transport pathways through the EBS are generally diffusive and their properties are treated as uncertain. Solubility limits significantly control the rate of radionuclide diffusion as they define the concentration gradient through which radionuclides may diffuse. Solubility limits are treated as uncertain except for those radionuclides that are not solubility limited, such as $^{99}\text{Tc}$ (Section 6.3.7.5). Finally, the sorption of radionuclides onto stationary corrosion products from the degraded WPs and internal structural supports is treated as uncertain and affects the release of those radionuclides that are highly sorbed on iron substrates.

To illustrate the resulting uncertainty associated with the release of radionuclide activity (in curies) from the EBS, radionuclide-specific release plots for $^{99}\text{Tc}$ and $^{239}\text{Pu}$ are presented on Figures 8.3-14[a] and 8.3-15[a] for the combined Nominal/Early Failure Modeling Case and both
the first 10,000 year time period and the post-10,000 year time period. Shown on each plot are the mean total inventory for that radionuclide along with the mean release curve and 5th and 95th percentile release curves. These plots illustrate that the mean release is affected by the range of the values of the uncertain parameters used in the analysis as summarized above. As illustrated, the mean release is typically close to the 95th percentile of the uncertain results indicating that the mean release is determined by a relatively few realizations with comparatively large releases. The uncertainty in $^{99}$Tc and $^{239}$Pu releases prior to 200,000 years is dominated by uncertain parameters that determine the number of early failure WPs and DSs, the degradation rates of HLW glass and CSNF, and the diffusive transport of $^{99}$Tc and $^{239}$Pu from the waste form to the WP outer barrier (Appendix K, Section K5.3 of the parent document). In addition, uncertainty in the release of $^{239}$Pu is also influenced by uncertain parameters that determine the solubility of plutonium and sorption of $^{239}$Pu onto stationary corrosion products.

Activity Releases from Engineered Barrier System Due to Seismic Ground Motion Damage of Engineered Barrier System Components

Many of the aspects of EBS performance under nominal and early failure conditions summarized in the preceding discussion are relevant to the Seismic GM Modeling Case. The following factors indicate EBS performance for the Seismic GM Modeling Case:

- Prior to about 170,000 years, radionuclide releases from the EBS are determined by processes related to vibratory ground motion-induced WP failures. The mean release from these processes is significantly greater than the mean release from the combined Nominal/Early Failure Modeling Case (Figure 8.3-13[a] and Figure 8.3-16[a]).
- Between 170,000 to 600,000 years, radionuclide releases from the EBS are determined by contributions from both nominal and vibratory ground motion-induced DS and WP failures (Figure 8.3-8[a]).
- After about 600,000 years, radionuclide releases from the EBS are determined primarily by processes related to the failure of WPs from nominal general corrosion processes (Figure 8.3-6[a]).
- Seismically-induced SCC of the CSNF WPs is not likely to occur before approximately 61,000 years (Figure 8.3-9[a]), whereas breaches of CDSP WPs may occur much earlier (Figure 8.3-10[a]). For purposes of comparison, based on the 95th percentile, nominal corrosion breaches of the CSNF and CDSP WPs are not likely to occur before about 170,000 years (Figure 8.3-6[a]); these breaches, however, are due to nominal process SCC in the closure-lid weld region.
- DS failures by combined seismically-induced rupture and general corrosion are largely distributed between about 40,000 and 300,000 years (Figure 8.3-7[a]) as compared to DS failures by general corrosion alone (under nominal conditions), which are distributed from about 270,000 to 340,000 years (Figure 8.3-4[a]).
• Vibratory ground motion-induced drift collapse during the post-10,000-year period causes the mean seepage fraction to increase to 70 percent as compared to the mean value of 40 percent in the Nominal Modeling Case (Table 8.3-5[a] and Table 8.3-3[a]).

• Much of the mobilized plutonium sorbs onto stationary corrosion products, and its subsequent release depends on the rates of desorption from the corrosion products (Section 6.3.8 of the parent document and Figures 7.7.1-6[a] and 7.7.1-8[a]). $^{242}$Pu is a key contributor to expected dose late in the post-10,000-year period (Section 8.1.1.5[a] and Figure 8.2-12[a]).

The EBS capability to prevent or reduce the release of radionuclides in the presence of seismic damage is shown on Figure 8.3-16[a] for both compliance periods.

In the Seismic GM Modeling Case, the CDSP WPs are much more likely to be damaged during 10,000 years after closure (Figure 8.3-8[a]) because the CSNF WPs are much stronger and more failure resistant (Section 7.3.2.6.1). The CSNF WPs include two inner stainless-steel vessels instead of one: namely, an inner vessel and its lid that is similar to the CDSP WPs and an additional stainless-steel TAD canister (SNL 2007 [DIRS 179394], Table 4-3). During the first 10,000 years after closure, the predominant mechanism that causes damage to CDSP WPs is SCC by vibratory ground motion-induced residual stresses in the WP OCB (Figure 8.3-10[a]). The DSs remain intact for seismic events occurring in the first 10,000 years (Figure 8.3-7[a]). As a result, dripping seepage cannot contact the WPs. Therefore, water enters the WP only by vapor diffusion through the cracks in the WP OCB. As CDSP WPs cool and the DSNF and HLW degrade, water films form on WP internals, permitting the diffusive transport of radionuclides through the small cracks and into the invert (Section 6.3.8). Comparing estimates of EBS release of $^{99}$Tc shown on Figure 8.3-13[a] with Figure 8.3-16[a] indicates a reduction in EBS capability to retain $^{99}$Tc by a factor of about 70 as compared to the combined Nominal/Early Failure Modeling Case. However, the comparison still indicates substantial and similar EBS capability during 10,000 years after closure for the less mobile radionuclides.

Estimates of the EBS release shown on Figure 8.3-16b[a] indicate a reduction in the EBS capability to retain $^{99}$Tc by a factor of about 140 at 100,000 years as compared to the combined Nominal/Early Failure Modeling Case. There is also a reduction in EBS capability by a factor of between 4 and 10 for less mobile radionuclides at 100,000 years and one million years, including $^{226}$Ra, $^{242}$Pu, and $^{237}$Np, which are key contributors to dose during the post-10,000-year period. Note that the activity of these radionuclides increases substantially after about 600,000 years when failure of the WPs by general corrosion processes begin to occur. By one million years, the total activity released in both the Seismic GM Modeling Case and the combined Nominal/Early Failure Modeling Case is approximately the same (Figures 8.3-13b[a] and 8.3-16b[a]), indicating that the overall reduction in barrier capability in each case, in terms of total activity released (Figure 8.3-1[a]), is about a factor of 10 after one million years.

The performance of the EBS in preventing or substantially reducing the rate of radionuclide release to the lower natural barrier as a result of combined seismic ground motion-induced degradation and nominal degradation processes is a function of several features and uncertain processes in the EBS. Similar to the combined Nominal/Early Failure Modeling Case, the degree of degradation of the WP controls the amount and rate of water that may enter the WP.
and potentially allow degradation of the waste form. The degree of WP degradation is highly uncertain and spatially variable and is significantly influenced by the magnitude and timing of seismic ground motions that are also uncertain. After about 600,000 years (Figure 8.3-11[a]), radionuclide releases from the EBS begin to be determined primarily by processes related to the failure of WPs from nominal processes. Again thermal, chemical, waste-form degradation, and transport processes determine the radionuclide releases from the EBS once WPs are breached. The uncertainty in these processes contributes uncertainty to the projected radionuclide releases from the EBS.

To illustrate the uncertainty associated with the release of radionuclide activity from the EBS, radionuclide-specific release plots for selected radionuclides are presented on Figures 8.3-17[a] to 8.3-22[a] for Seismic GM Modeling Case (which includes degradation processes by nominal general corrosion processes):

- Figure 8.3-17[a]: $^{99}$Tc
- Figure 8.3-18[a]: $^{237}$Np
- Figure 8.3-19[a]: $^{234}$U
- Figure 8.3-20[a]: $^{226}$Ra
- Figure 8.3-21[a]: $^{239}$Pu
- Figure 8.3-22[a]: $^{242}$Pu.

The results in these figures are expected releases (averaged over the aleatory uncertainties) and thus largely reflect the influence of epistemic uncertainties. This series of plots is presented to illustrate the impact of uncertainties on the projections of the EBS radionuclide releases. As can be noted from these plots, the EBS releases for all six radionuclides corresponding to the 95th percentile are consistently close to the corresponding mean release curves but are distant from the 5th percentile curves. This demonstrates that the mean releases are determined by expected releases for a relatively small number of epistemic sample elements for which the expected releases are comparatively large.

### 8.3.3.3[a] Lower Natural Barrier

As noted earlier, the lower natural barrier component (Section 8.3.2.3) of the repository system includes: (1) the UZ below the repository horizon, and (2) the SZ below the repository that extends downgradient from the repository footprint to the accessible environment. The role of the lower natural barrier is to prevent or substantially reduce the rate of movement of radionuclides from the repository to the accessible environment. The lower natural barrier performs this role through the intrinsic site characteristics that are directly reflected by such factors and processes as:

- Slow advective water transport
- Matrix diffusion and sorption of dissolved phase radionuclides
- Dispersion/dilution of dissolved and colloidal phase radionuclides
- Reversible filtration of colloids that have irreversibly sorbed radionuclides.

These intrinsic site characteristics along with radioactive decay properties of individual radionuclides determine the projected capability of the lower natural barrier. Insights to the
To ensure that the capability of the lower natural barrier was examined for a range of release conditions, two demonstration modeling cases were selected:

1. Combined Nominal/Early Failures
2. Seismic GM, including nominal corrosion processes.

The combined Nominal/Early Failure Modeling Case provides insight to barrier capability to reduce radionuclide movement for conditions of early releases from a few early-failed WPs and late releases (e.g., from general corrosion patch penetrations after ~ 400,000 years) from a large number of WPs. The Seismic GM Modeling Case examines the lower natural barrier’s capability to reduce radionuclide movement for conditions of releases distributed over both the 10,000-year and post-10,000-year time periods. As described in Section 8.3.3.2[a], the radionuclide releases computed for the Seismic GM Modeling Case occur from a variety of breach modes (e.g., seismic induced SCC cracking, rupture/puncture, and general corrosion patches).

To provide a metric of barrier effectiveness, the activity (in curies) of each radionuclide released from the UZ and SZ was computed using the TSPA-LA Model and the balance equations:

\[
\bar{R}_{UZ,k}(t \mid e) = \bar{A}_{T,k}(t \mid e) - (\bar{A}_{WP,k}(t \mid e) + \bar{A}_{I,k}(t \mid e) + \bar{A}_{UZ,k}(t \mid e)) \quad (\text{Eq. 8.3.3-3}[a])
\]

\[
\bar{R}_{SZ,k}(t \mid e) = \bar{A}_{T,k}(t \mid e) - (\bar{A}_{WP,k}(t \mid e) + \bar{A}_{I,k}(t \mid e) + \bar{A}_{UZ,k}(t \mid e) + \bar{A}_{SZ,k}(t \mid e)) \quad (\text{Eq. 8.3.3-4}[a])
\]

where \( \bar{R}_{UZ,k}(t \mid e) \) and \( \bar{R}_{SZ,k}(t \mid e) \) are the expected activities (in curies) of releases of radionuclide \( k \) from the UZ and SZ, respectively. The term \( \bar{A}_{T,k}(t \mid e) \) is the expected total activity of radionuclide \( k \) in the inventory (initial inventory decayed through time); \( \bar{A}_{WP,k}(t \mid e) \) is the expected activity of radionuclide \( k \) in a WP (including the activity in undegraded waste forms); \( \bar{A}_{I,k}(t \mid e) \) is the expected activity of radionuclide \( k \) in the invert; \( \bar{A}_{UZ,k}(t \mid e) \) is the expected activity of radionuclide \( k \) in the UZ; and \( \bar{A}_{SZ,k}(t \mid e) \) is the expected activity of radionuclide \( k \) in the SZ.

The means of the quantities \( \bar{R}_{UZ,k}(t \mid e) \) and \( \bar{R}_{SZ,k}(t \mid e) \) are denoted by \( \bar{\bar{R}}_{UZ,k}(t) \) and \( \bar{\bar{R}}_{SZ,k}(t) \), respectively, and are compared with the mean EBS releases, \( \bar{\bar{R}}_{EBS,k}(t) \), to provide an indication of barrier capability. The mean percent reduction (\( \bar{PR} \)) in activity achieved by the UZ alone and by the lower natural barrier as a whole is estimated from the equations:

\[
\bar{PR}_{UZ,k} = \left(1 - \left[\frac{\bar{R}_{UZ,k}}{\bar{R}_{EBS,k}}\right]\right) \times 100 \quad \text{(Eq. 8.3.3-5[a])}
\]
Total System Performance Assessment Model/Analysis for the License Application

\[
PR_{LNB,k} = \left( 1 - \frac{\overline{R}_{SZ,k}}{\overline{R}_{EBS,k}} \right) \times 100 \quad \text{(Eq. 8.3.3-6[a])}
\]

where \( \overline{R}_{EBS,k} \), \( \overline{R}_{UZ,k} \), and \( \overline{R}_{SZ,k} \) are the peak values (at any time) of the mean activity release of radionuclide \( k \) within the time period under consideration (i.e., time 0 to 10,000 years and 10,000 years to 1,000,000 years). The calculations of \( PR_{UZ,k} \) and \( PR_{LNB,k} \), which are presented below, can be found in output DTN: MO0701PLOTSFIG.000 ([DIRS 185207], Releases from UZ & SZ updated.xls).

In the special case of decay chain radionuclides, the quantities \( \overline{R}_{UZ,k}(t \mid e) \) and \( \overline{R}_{SZ,k}(t \mid e) \) are typically dominated by ingrowth rather than transport of the individual species. This is the case for \(^{230}\text{Th}\) and \(^{226}\text{Ra}\); their activities in the lower natural barrier are generally in secular equilibrium with their respective precursors according to the simple decay chain:

\[
^{234}\text{U} \text{ (half-life 240,000 yrs)} \rightarrow ^{230}\text{Th} \text{ (half-life 77,000 yrs)} \rightarrow ^{226}\text{Ra} \text{ (half-life 1,600 years)}.
\]

Both \(^{230}\text{Th}\) and \(^{226}\text{Ra}\) move through the lower natural barrier at significantly slower rates than their precursor \(^{234}\text{U}\) (SNL 2008 [DIRS 183750], Table 6.10[a]). As a result, their activities are primarily determined by the chain decay process as opposed to by groundwater transport of their individual species. As documented in Section 6.3.7 of the parent document and Sections 6.3.9[a] and 6.3.10[a], the radionuclide half-life values used in the EBS, UZ, and SZ submodels are from DTN: MO0702PASTREAM.001_R0 [DIRS 179925]. The following discussion uses these half-life values (Table 6.3.9-1[a]).

**Basis for Lower Natural Barrier Capability Projections**—The conceptual models and mathematical basis for the UZ and SZ transport can be found in Sections 6.3.9 and 6.3.10; those sections also describe the implementation of the UZ and SZ abstractions in the overall TSPA-LA Model. The simulation methodology and abstractions of dissolved and colloidal phase transport are documented in: (1) *Particle Tracking Model and Abstraction of Transport Processes* (SNL 2008 [DIRS 184748]), which describes the UZ transport simulation model; (2) *Site-Scale Saturated Zone Transport* (SNL 2008 [DIRS 184806]); and (3) *Saturated Zone Flow and Transport Model Abstraction* (SNL 2008 [DIRS 183750]), which collectively describe the SZ transport simulation model. The experimental data used to characterize UZ and SZ transport model parameters are documented in *Radionuclide Transport Models Under Ambient Conditions* (SNL 2007 [DIRS 177396]).

The TSPA-LA Model uses a Monte Carlo simulation methodology that incorporates aleatory and epistemic uncertainties into the projections. For the combined Nominal/Early Failure Modeling Case, the epistemic loop performs 300 realizations. For the Seismic GM Modeling Case, the probabilistic projections are based on 9,000 realizations consisting of 300 epistemic and 30 aleatory realizations. The aleatory and epistemic sample elements are the same as those used in the analyses presented in Section 8.3.3.2[a].
8.3.3.3.1[a] Capability of Lower Natural Barrier to Prevent or Substantially Reduce the Rate of Radionuclide Movement

A demonstration of lower natural barrier capability was developed using the TSPA-LA Model to simulate radionuclide movement from the EBS through the combined UZ and SZ groundwater path. The UZ portion includes the Topopah Springs welded (TSw) and Calico Hills nonwelded (CHn) tuffs of the Crater Flat Group. Within the repository footprint, the present-day water table varies from around 730 m to 850 m above mean sea level (BSC 2004 [DIRS 169855], Figure 6.2). For wetter climates such as the monsoon and glacial-transition climates, a water table rise up to 120 m for the wetter climate reduces the length of the UZ transport path (Section 6.3.9). The SZ flow path, which extends 18 km from below the repository footprint to the accessible environment boundary, is composed of volcanic units and alluvium (Section 6.3.10). The projected groundwater transport pathway is southeast from the repository site, transitioning to a southerly direction towards the designated accessible environment boundary in the Amargosa Desert. The first 12 to 14 km of the SZ flow path is in fractured volcanic rocks; the remainder of the 18-km flow path is composed of alluvium. The model components of the TSPA-LA Model account for transport in fractured-porous media and are based on: (1) a dual-continuum approach for the UZ (Section 6.3.9.2), and (2) a dual-porosity approach for the fractured volcanic units and an equivalent-continuum approach for the alluvium in the SZ (SNL 2008 [DIRS 183750], Section 6.3.1).

Probabilistic projections of radionuclide releases for the 12 representative radionuclides selected in Section 8.3.1[a] are used to compute the radionuclide releases (in Ci) (from Equation 8.3.3-3[a] and Equation 8.3.3-4[a]) and mean activity reductions (from Equation 8.3.3-5[a] and Equation 8.3.3-6[a]). The radionuclides considered are: $^{137}$Cs, $^{90}$Sr, $^{241}$Am, $^{240}$Pu, $^{99}$Tc, $^{239}$Pu, $^{242}$Pu, $^{237}$Np, $^{238}$U, $^{233}$Am, $^{230}$Th, and $^{226}$Ra. Of these 12 radionuclides, five are transported in the dissolved phase and reversibly and irreversibly sorbed to colloids, namely: $^{241}$Am, $^{240}$Pu, $^{239}$Pu, $^{242}$Pu, and $^{233}$Am. The calculations of radionuclide release reductions are based on the total activity of these radionuclides, designated with superscript T; it is noteworthy to mention that the activity releases for these five radionuclides are dominated by the dissolved phase activities.

Barrier Capability for Combined Nominal/Early Failure Modeling Case—The aim of this performance demonstration is to estimate the natural barrier capability for a broad range of undisturbed conditions (i.e., in the absence of disruptive events). As will be shown, the early failures of DSs and WPs produce relatively low mean releases starting immediately at repository closure and persisting for the simulated time period of 1,000,000 years. Added to these releases are radionuclides released due to DS and WP failure by nominal processes that mainly occur in the post-10,000-year period (Section 8.3.3.2.1[a]); these failures ultimately lead to relatively large advective radionuclide releases from a large number of WPs.

Projections of Barrier Capability for 10,000 Years after Closure—The projected mean activity releases from the lower natural barrier, specifically $\bar{R}_{SZ,k}(t)$, are shown on Figure 8.3-23[a] for the combined Nominal/Early Failure Modeling Case; this figure also shows the corresponding plot for the projected releases from the EBS for 10,000 years after closure (Figure 8.3-23b[a]). At 10,000 years, the mean of total activity released from the SZ (summed
over all radionuclides) is approximately 6 Ci, compared to the mean total activity released from the EBS of about 15 Ci and the mean total activity in the inventory of about $4 \times 10^7$ Ci. $^{99}$Tc comprises most of the mean total release from the EBS. Figure 8.3-23[a] indicates an overall reduction in activity release due to the lower natural barrier of about 60 percent, although the reduction varies widely for individual radionuclides, as discussed next.

As shown on Figure 8.3-23b[a], the shapes of the curves for various radionuclides released from the EBS vary as a function of time. The variation in shape provides insights into the capability of the EBS to prevent or reduce the rate of movement of radionuclides from the repository to the lower natural barrier and how this capability changes with time. The slope of the activity release curve for a given radionuclide changes with time and typically starts with a positive slope that gradually decreases to zero prior to becoming negative. This shape is attributed to the interplay of the release rate of a radionuclide from the EBS (or mass retention rate in the EBS) compared to its radioactive decay rate. As shown in Equation 8.3.3-1[a], the activity release of a given radionuclide from the EBS is computed by taking the difference between the activity of the emplaced inventory and that retained in the EBS. The positive slope in the activity release curve indicates that the rate of mass release from the EBS is greater than the effective rate of decay of the emplaced mass, where the effective rate of decay accounts for any ingrowth from decay of a parent radionuclide. A positive slope typically occurs when the release rate out of the EBS is large. When the slope is zero, the release rate from the EBS is the same as the effective decay rate; a negative slope occurs when mass is released from the EBS slower than the effective rate of decay. This is typically the case when the EBS release rate becomes negligible and the slope of the activity release curve approaches the rate of change corresponding to the effective decay rate.

In comparing the peak mean activity radionuclide releases for the large initial inventory group (Section 8.3.1[a]): $^{137}$Cs (transported as a solute and reversibly sorbed on colloids); $^{90}$Sr (transported as a solute); $^{241}$Am (transported as a solute and reversibly and irreversibly sorbed on colloids); and $^{240}$Pu (transported as a solute and reversibly and irreversibly sorbed on colloids); the calculations of $\tilde{PR}_{LNB,A}$ indicate that the lower natural barrier effectively accounts for the following reductions in the activity released from the EBS:

- $^{137}$Cs (half-life 30.1 yrs): ~100 percent reduction (from ~40 µCi to ~0 µCi)
- $^{90}$Sr (half-life 28.8 yrs): ~100 percent reduction (from ~7 µCi to ~0 µCi)
- $^{241}$Am (half-life 433 yrs): ~99.9 percent reduction (from ~3 mCi to ~4 µCi)
- $^{240}$Pu (half-life 6,560 yrs): ~99.5 percent reduction (from ~17 mCi to ~80 µCi).

The barrier effectiveness of the UZ is supported by detailed particle tracking calculations (SNL 2008 [DIRS 184748], Sections 6.6.2.1[a], [b], and 6.6.2.2[a], [b]) that indicate mean water transport times (to the water table) from the southern part of the repository on the order of 400 years or longer, which means that any mass of $^{137}$Cs and $^{90}$Sr released in the southern part of the repository would experience more than 10 half-lives of decay before reaching the water table. Mean transport times from northern repository locations, however, are shorter because of the predominance of flow through fractures. In addition, calculations for the SZ (SNL 2008 [DIRS 183750], Table 6-10[a]) indicate median radionuclide transport times ranging from 42,000 years to greater than 1,000,000 years for cesium species and from 9,000 years to greater
than 1,000,000 years for strontium species (SNL 2008 [DIRS 183750], Table 6-10[a]). In the case of $^{241}$Am and $^{240}$Pu, reductions in radionuclide activity released are primarily the result of retardation effects arising from a combination of (1) mean seepage fractions that are less than 0.5 (Table 8.3-2[a]), indicating that (on average) more than half of the mass released from the EBS diffuses into the matrix of the UZ; (2) sorption of dissolved phase radionuclides, reversible exchanges from dissolved to colloidal phases, and reversible colloidal filtration; and (3) radionuclide decay occurring during transport through the lower natural barrier.

For $^{99}$Tc (half-life $2.13 \times 10^5$ yrs), $PR_{LNB,k}$ indicates a reduction of about 62 percent within 10,000 years (~14 Ci to ~5.3 Ci), with the UZ accounting for about three quarters of this reduction. The level of activity reduction of this non-sorbing radionuclide indicates a significant degree of transport through the rock matrix occurring during the first 10,000 years. This effectiveness of the lower natural barrier is due to the interplay of radionuclide transport through the invert and rock matrix, matrix diffusion between fractures and matrix of the UZ, and matrix diffusion in the volcanic units of the SZ in combination with transport time in the SZ. Median transport time for technetium through the SZ is estimated to range from 10 years to about 22,000 years, which means that the capability of the SZ to reduce the rate of movement would be limited for the 10,000-year compliance period. These release characteristics for other highly soluble and non-sorbing radionuclides with long half-lives, such as $^{129}$I, are expected to be similar to those of $^{99}$Tc.

Regarding projections of $PR_{LNB,k}$ for radionuclides in the category of low to moderate solubility, low sorption, and long half-life, such as $^{239}$Pu, $^{242}$Pu, $^{237}$Np, and $^{234}$U, the reductions in peak mean activities released are estimated to be:

- $^{239}$Pu (half-life $2.41 \times 10^4$ yrs): ~99.6 percent reduction (from ~60 mCi to ~0.3 mCi)
- $^{242}$Pu (half-life $3.75 \times 10^5$ yrs): ~99.1 percent reduction (from ~62 µCi to ~0.5 µCi)
- $^{237}$Np (half-life $2.14 \times 10^6$ yrs): ~78 percent reduction (from ~0.3 mCi to ~77 µCi)
- $^{234}$U (half-life $2.46 \times 10^7$ yrs): ~89 percent reduction (from ~0.1 mCi to ~16 µCi).

With the half-lives of these radionuclides being much greater than 10,000 years, the projected reductions in the activity are primarily attributed to delay in the subsurface transport produced by: (1) the combined processes of matrix diffusion and sorption in the UZ, and (2) matrix diffusion and sorption in volcanic units and sorption in the alluvium of the SZ. With regard to $^{239}$Pu and $^{242}$Pu, the percent reductions are nearly the same because they have the same sorption properties.

For $^{243}$Am, $^{230}$Th, and $^{226}$Ra, the projected reductions in peak mean activity achieved by the lower natural barrier within 10,000 years after closure are estimated to be:

- $^{243}$Am (half-life 7,370 yrs): ~99.8 percent reduction (from ~2 mCi to ~4 µCi)
- $^{230}$Th (half-life 7.54 $\times 10^4$ yrs): ~99.4 percent reduction (from ~76 µCi to ~0.5 µCi)
- $^{226}$Ra (half-life 1,600 yrs): ~99.9 percent reduction (from ~0.6 mCi to ~0.3 µCi).

More than half of the projected activity reductions in the lower natural barrier are achieved by the UZ. These large reductions occur due to very strong sorption in both the zeolitic and
devitrified tuff layers (Table 6.3.9-2) of the UZ, as well as in the volcanic units and alluvium (Table 6.3.10-2) of the SZ.

**Projections of Barrier Capability for Post-10,000 Years after Closure**—The plot for the projected mean activity released from the lower natural barrier for the combined Nominal/Early Failure Modeling Case is shown on Figure 8.3-24[a]. Also shown on this figure, is the corresponding projection for mean activity released from the EBS. The peak mean total activity released from the SZ (summed over all radionuclides) is approximately $2.8 \times 10^4$ Ci at 800,000 years, compared to the peak mean total activity released from the EBS of about $4 \times 10^4$ Ci at 900,000 years. $^{99}$Tc comprises most of the mean total release from the EBS. Figure 8.3-24[a] indicates an overall reduction (peak to peak) in activity releases due to the lower natural barrier of about 30 percent.

Of the four radionuclides in the large inventory group (i.e., $^{137}$Cs, $^{90}$Sr, $^{241}$Am, and $^{240}$Pu), the inventories for $^{137}$Cs and $^{90}$Sr are essentially depleted by radioactive decay by 1,000 years (e.g., more than 30 half-lives of decay) after closure (Figure 8.3-1[a]). As a result, there would be no releases of these radionuclides from the EBS or SZ in the post-10,000-year period. In the case of $^{241}$Am and $^{240}$Pu, however, their total repository inventories are still substantial at 10,000 years (i.e., approximately $1.4 \times 10^4$ Ci for $^{241}$Am and $1.6 \times 10^7$ Ci for $^{240}$Pu) (Figure 8.3-1[a]). Consequently, releases of these radionuclides occur until about 150,000 years.

The calculations of $\overline{PR_{LNB,k}}$ for the post-10,000-year period show the following reductions in the peak mean activity of $^{241}$Am and $^{240}$Pu:

- $^{241}$Am (half-life 433 yrs): ~100 percent reduction (from ~0.2 mCi to ~0 mCi)
- $^{240}$Pu (half-life 6,560 yrs): ~98 percent reduction (from ~60 mCi to ~1 mCi).

These activity reductions are similar to those projected for the 10,000-year period. Moreover, most of the $^{241}$Am activity reduction is accounted for by the UZ portion of the lower natural barrier. In the case of $^{240}$Pu, the UZ accounts for about 50 percent of the reduction.

For $^{99}$Tc (half-life $2.13 \times 10^5$ yrs), the lower natural barrier achieves a reduction of about 5 percent (from ~$2.8 \times 10^4$ Ci to ~$2.6 \times 10^4$ Ci) at 1,000,000 years. This reduction is predominantly the result of matrix diffusion in the rock layers of the UZ and the volcanic units of the SZ. This activity reduction is considerably smaller than the reductions projected for the 10,000-year period; however, this is due to the fact that the technetium released from the EBS in the first 10,000-year period may not have been released from the SZ within 10,000 years. Note that for $^{99}$Tc, the travel time ranges between 10 and 22,190 years within the SZ with a median travel time of 230 years (SNL 2008 [DIRS 183750], Table 6-10[a]). Regarding projections of $\overline{PR_{LNB,k}}$ for radionuclides in the category of low to moderate solubility, low sorption, and long half-life, such as $^{239}$Pu, $^{242}$Pu, $^{237}$Np, and $^{234}$U, the reductions in peak mean activities released are lower than those for the 10,000-year period. The projected percent reductions are:

- $^{239}$Pu (half-life $2.41 \times 10^4$ yrs): ~90 percent reduction (from ~0.8 Ci to ~0.08 Ci)
- $^{242}$Pu (half-life $3.75 \times 10^5$ yrs): ~66 percent reduction (from ~44 Ci to ~15 Ci)
• $^{237}$Np (half-life $2.14 \times 10^6$ yrs): ~23 percent reduction (from ~16 Ci to ~13 Ci)
• $^{234}$U (half-life $2.46 \times 10^5$ yrs): ~32 percent reduction (from ~1.5 Ci to ~1 Ci).

With regard to $^{239}$Pu and $^{242}$Pu, the percent reductions are distinct because of the effects of radioactive decay and $^{239}$Pu having a small half-life compared to the 1,000,000-year time period. The UZ accounts for almost half of the reduction in $^{239}$Pu and $^{242}$Pu activities. In contrast, the UZ accounts for only about one-third of the reduction in $^{237}$Np and $^{234}$U activities.

In the case of $^{243}$Am, $^{230}$Th, and $^{226}$Ra, the projected reductions achieved by the lower natural barrier are comparable to those for the 10,000-year period. They are estimated to be:

• $^{243}$Am (half-life 7,370 yrs): ~99.6 percent reduction (from ~0.2 Ci to ~0.7 mCi)
• $^{230}$Th (half-life $7.54 \times 10^4$ yrs): ~85 percent reduction (from ~4.5 Ci to ~0.7 Ci)
• $^{226}$Ra (half-life 1,600 yrs): ~97.6 percent reduction (from ~28 Ci to ~0.7 Ci).

The UZ portion of the lower natural barrier accounts for about 40 percent of the $^{230}$Th activity reduction and about 80 percent of the activity reduction for $^{243}$Am$^T$ and $^{226}$Ra.

**Barrier Capability for Seismic Ground Motion Modeling Case**—The intent of this demonstration modeling case is to examine the capability of the lower natural barrier under conditions of EBS releases attributed to vibratory ground motion events (i.e., disruptive events). The Seismic GM Modeling Case is particularly relevant because it was shown to be important to projections for the Individual Protection Standard (Section 8.1.1.2[a]). In this demonstration modeling case, damage and failure of the DSs and WPs occur as a result of vibratory ground motion and nominal corrosion processes. Moreover, the WP breach modes are quite varied, including seismic-induced SCC, rupture and puncture, as well as general corrosion penetration of the WP OCB and SCC of the closure-lid welds. These breach modes ultimately lead to a broad range of slow diffusive and fast advective releases to the lower natural barrier.

**Projections of Barrier Capability for 10,000 Years after Closure**—The projected mean activity released from the lower natural barrier is shown on Figure 8.3-25[a]; also shown on this figure is the corresponding plot for the projected releases from the EBS for 10,000 years after closure. At 10,000 years, the mean of total activity released from the SZ (summed over all radionuclides) is approximately 540 Ci, compared to the mean total activity released from the EBS of about 1,200 Ci and the mean total activity in the inventory of about $4 \times 10^7$ Ci. $^{90}$Tc comprises most of the mean total release from the EBS. Figure 8.3-25[a] indicates an overall reduction in activity releases due to the lower natural barrier of about 55 percent, although the reduction varies widely for individual radionuclides, as discussed next.

In comparing the peak mean activity radionuclide releases for the large initial inventory group (Section 8.3.1[a]): $^{137}$Cs (transported as a solute and reversibly sorbed on colloids); $^{90}$Sr (transported solute); $^{241}$Am$^T$ (transported as a solute and reversibly and irreversibly sorbed on colloids); and $^{240}$Pu$^T$ (transported as a solute and reversibly and irreversibly sorbed on colloids); the calculations of $PR_{LNB,k}$ indicate that the lower natural barrier effectively accounts for the following reductions in the peak mean activity:

• $^{137}$Cs (half-life 30.1 yrs): ~100 percent reduction (from ~0.6 µCi to ~0 µCi)
• $^{90}\text{Sr}$ (half-life 28.8 yrs): ~100 percent reduction (from ~0.03 µCi to ~0 µCi)
• $^{241}\text{Am}$ (half-life 433 yrs): ~100 percent reduction (from ~73 µCi to ~0 µCi)
• $^{240}\text{Pu}$ (half-life 6,560 yrs): ~99.6 percent reduction (from ~15 mCi to ~55 µCi).

These percent reductions are almost identical to those estimated for the combined Nominal/Early Failure Modeling Case. Also similar is the fact that the UZ accounts for very significant reductions (e.g., 80 to 88 percent) of $^{137}\text{Cs}$, $^{90}\text{Sr}$, and $^{241}\text{Am}$ activities. It is worth noting that although the percent reductions are similar, the EBS releases for the Seismic Ground Motion are much higher than those for the combined Nominal/Early Failure Modeling Case (Figure 8.3-23[a]).

The mean activity reduction projected for $^{99}\text{Tc}$ (half-life $2.13 \times 10^5$ yrs) for the first 10,000 years is approximately 55 percent (from 941 Ci to 427 Ci), with more than half of the reduction provided by the UZ (output DTN: MO0710PLOTSFIG.000 [DIRS 185207], Releases from UZ & SZ Updated.xls). This level of activity reduction for $^{99}\text{Tc}$ is similar to that for the combined Nominal/Early Failure Modeling Case, but the curies released in the Seismic Modeling Case are much higher.

The percent reductions projected for $^{239}\text{Pu}$, $^{242}\text{Pu}$, $^{237}\text{Np}$, and $^{234}\text{U}$ for the lower natural barrier are as follows:

• $^{239}\text{Pu}$ (half-life $2.41 \times 10^4$ yrs): ~99.6 percent reduction (from ~48 mCi to ~0.2 mCi)
• $^{242}\text{Pu}$ (half-life $3.75 \times 10^5$ yrs): ~99.6 percent reduction (from ~49 µCi to ~0.2 µCi)
• $^{237}\text{Np}$ (half-life $2.14 \times 10^6$ yrs): ~81 percent reduction (from ~0.1 mCi to ~20 µCi)
• $^{234}\text{U}$ (half-life $2.46 \times 10^5$ yrs): ~93 percent reduction (from ~0.3 mCi to ~22 µCi).

These percent reductions are very similar to those projected for the combined Nominal/Early Failure Modeling Case.

Finally, for $^{243}\text{Am}$, $^{230}\text{Th}$, and $^{226}\text{Ra}$, the projected reductions are estimated to be:

• $^{243}\text{Am}$ (half-life 7,370 yrs): ~100 percent reduction (from ~10 µCi to ~0 µCi)
• $^{230}\text{Th}$ (half-life $7.54 \times 10^4$ yrs): ~96.2 percent reduction (from ~11 µCi to ~0.4 µCi)
• $^{226}\text{Ra}$ (half-life 1,600 yrs): ~100 percent reduction (from ~30 mCi to ~0.6 µCi).

These percent reductions are also very similar to those projected for the combined Nominal/Early Failure Modeling Case.

**Projections of Barrier Capability for Post-10,000 Years after Closure**—The plot for the projected mean activity released from the lower natural barrier is shown on Figure 8.3-26[a]; this figure also shows the corresponding projection for mean activity released from the EBS. The peak mean total activity released from the SZ (summed over all radionuclides) is approximately $3 \times 10^4$ Ci at 800,000 years; compared to the peak mean total activity released from the EBS of about $5 \times 10^4$ Ci at 800,000 years. $^{99}\text{Tc}$ comprises most of the mean total release from the EBS. Figure 8.3-26[a] indicates an overall reduction (peak to peak) in activity releases due to the lower natural barrier of about 40 percent.
Of the four radionuclides in the large inventory group (i.e., $^{137}$Cs, $^{90}$Sr, $^{241}$Am, and $^{240}$Pu), the inventories for $^{137}$Cs and $^{90}$Sr are essentially depleted by radioactive decay by 1,000 years (e.g., more than 30 half-lives of decay) after closure (Figure 8.3-1[a]). As a result, there would be no releases of these radionuclides from the EBS or SZ in the post-10,000-year period. In the case of $^{241}$Am and $^{240}$Pu, however, their total repository inventories are still substantial and estimated to be approximately $1.4 \times 10^4$ Ci for $^{241}$Am and $1.6 \times 10^7$ Ci for $^{240}$Pu remaining in the repository at 10,000 years after closure.

For the post-10,000-year period, the calculations of $\overline{PR}_{LNB,k}$ show the following reductions in the peak mean activity of $^{241}$Am and $^{240}$Pu:

- $^{241}$Am (half-life 433 yrs): ~100 percent reduction (from ~3 µCi to ~0 µCi)
- $^{240}$Pu (half-life 6,560 yrs): ~97 percent reduction (from ~0.1 Ci to ~4 mCi).

The UZ accounts for about half of the $^{241}$Am activity reductions and nearly all of the $^{240}$Pu activity reductions. These reductions are very similar to those estimated for the combined Nominal/Early Failure Modeling Case for the post-10,000-year period.

For $^{99}$Tc (half-life $2.13 \times 10^5$ yrs), the lower natural barrier is projected to achieve a reduction of about 5 percent (from $3.3 \times 10^4$ Ci to $3.1 \times 10^4$ Ci) at 1,000,000 years. This level of barrier effectiveness is similar to the reduction estimated for the combined Nominal/Early Failure Modeling Case for the post-10,000-year period.

Regarding projections for radionuclides in the category of low-to-moderate solubility; low sorption in the UZ and SZ; and long half-life, such as $^{239}$Pu, $^{242}$Pu, $^{237}$Np, and $^{234}$U; the reductions in peak mean activities released are less than those for the 10,000-year period. The projected percent reductions are:

- $^{239}$Pu (half-life 2.41 $\times 10^4$ yrs): ~88 percent reduction (from ~11 Ci to ~1.4 Ci)
- $^{242}$Pu (half-life 3.75 $\times 10^5$ yrs): ~70 percent reduction (from ~200 Ci to ~62 Ci)
- $^{237}$Np (half-life 2.14 $\times 10^6$ yrs): ~20 percent reduction (from ~100 Ci to ~81 Ci)
- $^{234}$U (half-life 2.46 $\times 10^6$ yrs): ~25 percent reduction (from ~14 Ci to ~10 Ci).

The UZ accounts for roughly half of the reductions in $^{239}$Pu and $^{242}$Pu activity; whereas for $^{237}$Np and $^{234}$U, it only accounts for about one-quarter of the reductions (output DTN: MO0710PLOTSFIG.000 [DIRS 185207], Releases from UZ & SZ Updated.xls). These reductions are very similar and consistent with those projected for the combined Nominal/Early Failure Modeling Case for the post-10,000-year time period.

In the case of the radionuclides $^{243}$Am, $^{230}$Th, and $^{226}$Ra, the projected reductions are comparable to those shown earlier for the combined Nominal/Early Failure Modeling Case for the post-10,000-year period. The reductions are estimated to be:

- $^{243}$Am (half-life 7,370 yrs): ~99.8 percent reduction (from ~3 mCi to ~8 µCi)
- $^{230}$Th (half-life 7.54 $\times 10^4$ yrs): ~89 percent reduction (from ~71 Ci to ~8 Ci)
- $^{226}$Ra (half-life 1,600 yrs): ~97 percent reduction (from ~260 Ci to ~8 Ci).
For these three radionuclides, the UZ accounts for one-half or more of the activity reductions (output DTN: MO0710PLOTSFIG.000 [DIRS 185207], Releases from UZ & SZ Updated.xls). Again, these reductions are consistent with those projected for the combined Nominal/Early Failure Modeling Case and post-10,000-year time period.

Uncertainty in Projections of Lower Natural Barrier Capability—Uncertainty in the projections of lower natural barrier capability is influenced by uncertainties in of the models for flow and transport processes. The TSPA-LA Model accounts for these epistemic uncertainties by using probabilistic representations of the input parameters in the component models for UZ flow, UZ transport, SZ flow, and SZ transport. In the case of UZ flow and transport (Section 6.3.9), the parameters of primary importance include (1) sorption coefficients for various radionuclides, (2) matrix diffusion coefficient, and (3) infiltration scenario. Important parameters related to groundwater flow (or advection) in the SZ (Section 6.3.10) are: (1) groundwater specific discharge, (2) flowing interval porosity, (3) alluvium effective porosity, and (4) horizontal anisotropy. The process of matrix diffusion is dependent on flowing interval spacing, effective diffusion coefficient, and matrix porosity. The process of radionuclide sorption on the fractured and porous media is a function of the sorption coefficients, bulk density and porosity for various radionuclides, and geologic media. Tables presented in Sections 6.3.9 and 6.3.10 summarize the values and uncertainty distributions for all parameters used in the UZ and SZ transport simulations.

To illustrate the uncertainty associated with the release of radionuclide activity from the lower natural barrier, radionuclide-specific release plots for selected radionuclides are presented on Figures 8.3-27[a] to 8.3-32[a] for combined nominal and seismic ground motion-induced degradation processes:

- Figure 8.3-27[a]: $^{99}$Tc
- Figure 8.3-28[a]: $^{237}$Np
- Figure 8.3-29[a]: $^{234}$U
- Figure 8.3-30[a]: $^{226}$Ra
- Figure 8.3-31[a]: $^{239}$Pu
- Figure 8.3-32[a]: $^{242}$Pu.

The results in these figures are expected releases (averaged over the aleatory uncertainties) and thus largely reflect the impact of epistemic uncertainties. These plots are presented to illustrate the impact of uncertainties on the projections of the lower natural barrier radionuclide releases. As can be noted from these plots, the lower natural barrier releases for all six radionuclides corresponding to the 95th percentile are consistently close to the corresponding mean release curves but are distant from the 5th percentile curves. The aleatory and epistemic sample elements are the same as those used in the analyses presented in Section 8.3.3.2[a].

8.3.3.4[a] Summary of Barrier Capability Demonstration

As illustrated on Figure 8-1 of the parent document, the multiple barriers of the Yucca Mountain repository system consist of three primary barriers: (1) upper natural barrier, (2) EBS, and (3) lower natural barrier. The upper natural barrier consists of the topography and surficial soils of the mountain, the unsaturated tuff units above the repository, and rock strata in which the
repository is constructed. The EBS includes the emplacement drifts, WPs, DSs, waste forms, cladding (associated with the CSNF, DSNF, and naval SNF), pallets, and the drift invert; no credit is taken, however, for cladding performance. The lower natural barrier below the repository includes the unsaturated rock layers beneath the repository as well as the volcanic rock units and the alluvium in the SZ, which extends from the repository site to the designated accessible environment boundary. Collectively, these three barriers function to:

1. Prevent or substantially reduce the rate of movement of water or radionuclides from the repository to the accessible environment, and

2. Prevent or substantially reduce the release of radionuclides from the repository.

Probabilistic projections for two demonstration modeling cases were developed to quantify the capability for the three primary barriers. These two demonstration modeling cases are: (1) combined Nominal/Early Failure Modeling Case (representative of the absence of disruptive events), and (2) Seismic GM Modeling Case (representative of the presence of disruptive events).

**Upper Natural Barrier**—Barrier capability analyses demonstrate that topography and surficial soils substantially reduce the net infiltration into the underlying UZ rock layers above the repository. For climate states projected for the first 10,000 years after closure, the topography and surficial soils prevent on average about 90 percent or more of the precipitation from entering the underlying UZ rock layers. More specifically, the mean net infiltration rate ($\bar{I}$) as a percentage of precipitation rate ($\bar{P}$) for each climate state is estimated to be: (1) present-day climate: $\bar{I} \sim 8.0$ percent of $\bar{P}$; (2) monsoon climate: $\bar{I} \sim 8.7$ percent of $\bar{P}$; and (3) glacial-transition climate: $\bar{I} \sim 10.4$ percent of $\bar{P}$.

Of the water ultimately reaching the repository horizon (i.e., Topopah Springs welded [TSw]), only a fraction of the local percolation would enter the emplacement drifts as a result of the capillary barrier effect. This capillary barrier effect diverts ambient water flow around the emplacement drifts (Section 6.3.1.1). Taking this effect into account, the mean drift seepage ($\bar{S}$) is less than 11 percent of mean annual percolation rate for intact drifts, and is less than 12 to 48 percent for degraded drifts, varying with the extent of drift degradation.

These seepage rate reductions indicate that very small fractions of the precipitation and ensuant net infiltration would enter the emplacement drifts.

**Engineered Barrier System**—The EBS prevents or substantially reduces the release rate of radionuclides from the waste forms and prevents or substantially reduces the rate of movement of radionuclides from the repository to the accessible environment. It performs these functions by virtue of the materials and design of the emplacement drifts, DSs, WPs and waste forms, and WP internals. In addition, the EBS provides for chemical and TH environments that lead to low solubilities for the radionuclides that make up the greatest fraction of the inventory activity. Finally, the EBS environments are such that radionuclide transport from the waste to the UZ is limited to a small fraction of the available inventory (less than $3 \times 10^{-3}$ percent in 10,000 years and 5 percent in 1 million years), even in the case of seismic-induced mechanical degradation.
**Lower Natural Barrier**—Projections of barrier capability demonstrate that for large initial inventory, soluble, and short half-life radionuclides, such as $^{137}$Cs and $^{90}$Sr, the mean activity released from the EBS would be reduced by 100 percent (i.e., they are highly unlikely to reach the accessible environment). For radionuclides with longer half-lives such as $^{241}$Am and $^{240}$Pu, the mean activity released would be reduced by 97 to 100 percent by the natural barrier. For radionuclides of low to moderate solubility, weak to strong sorption, and long half-life, such as $^{237}$Np, $^{242}$Pu, and $^{239}$Pu, mean activity released from the EBS would be reduced by 80 percent to 100 percent before reaching the accessible environment during the 10,000-year period and by 20 percent to 88 percent during the post-10,000-year period. In terms of total mean activity, the lower natural barrier reduces the total mean activity released (primarily due to highly soluble, long half-life, non-sorbing $^{99}$Tc) from the EBS by 55 percent for the 10,000-year period, and 5 percent for post-10,000-year period, respectively. These reductions of EBS releases would be achieved by the combination of lower natural barrier processes, including slow advective water transport, matrix diffusion and sorption of dissolved phase radionuclides, dispersion/dilution of dissolved and colloidal phase radionuclides, and reversible filtration of colloidal phase radionuclides, as well as radioactive decay.

The demonstration of barrier capability for the EBS and lower natural barrier was developed using the TSPA-LA Model. The values of the parameters used in the TSPA-LA Model are the same as those used in the demonstration of compliance with the individual and groundwater protection standards presented in Section 8.1[a]. Although uncertainty exists in the parameters and models of the relevant processes that affect the assessment of barrier capability, this uncertainty has been appropriately addressed in the assessments. In summary, these barrier capability projections demonstrate that the multiple barriers increase the confidence that the postclosure performance objectives specified in NRC Proposed Rule 10 CFR 63.113(b) and (c) [DIRS 180319] would be achieved.
### Table 8.3-2[a]. Seepage Fractions for CDSP and CSNF Waste Packages for Combined Nominal/Early Failure Modeling Case for Glacial-Transition Climate, 2,000 to 10,000 Years

<table>
<thead>
<tr>
<th>Percolation Subregion</th>
<th>Seepage Fraction for CDSP Waste Packages</th>
<th>Seepage Fraction for CSNF Waste Packages</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5th Percentile</td>
<td>Mean</td>
</tr>
<tr>
<td>Subregion Index</td>
<td>Quantile Range</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>p &lt; 0.05</td>
<td>0.0031</td>
</tr>
<tr>
<td>2</td>
<td>0.05 ≤ p &lt; 0.30</td>
<td>0.0261</td>
</tr>
<tr>
<td>3</td>
<td>0.30 ≤ p &lt; 0.70</td>
<td>0.0448</td>
</tr>
<tr>
<td>4</td>
<td>0.70 ≤ p &lt; 0.95</td>
<td>0.0453</td>
</tr>
<tr>
<td>5</td>
<td>p ≥ 0.95</td>
<td>0.0880</td>
</tr>
<tr>
<td>Repository Average</td>
<td></td>
<td>0.0441</td>
</tr>
</tbody>
</table>

Source: Output DTN: MO0710PLOTSTFIGS.000 [DIRS 185207], file: LA_v5.005_NC_000300_004_Seepage_Fraction.xls.

**NOTE:** The repository average values are based on weighted averages for each realization using the percolation subregion quantile ranges.

### Table 8.3-3[a]. Seepage Fractions for CDSP and CSNF Waste Packages for Combined Nominal/Early Failure Modeling Case for Post-10,000-Year Period

<table>
<thead>
<tr>
<th>Percolation Subregion</th>
<th>Seepage Fraction for CDSP Waste Packages</th>
<th>Seepage Fraction for CSNF Waste Packages</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5th Percentile</td>
<td>Mean</td>
</tr>
<tr>
<td>Subregion Index</td>
<td>Quantile Range</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>p &lt; 0.05</td>
<td>0.0092</td>
</tr>
<tr>
<td>2</td>
<td>0.05 ≤ p &lt; 0.30</td>
<td>0.0623</td>
</tr>
<tr>
<td>3</td>
<td>0.30 ≤ p &lt; 0.70</td>
<td>0.0933</td>
</tr>
<tr>
<td>4</td>
<td>0.70 ≤ p &lt; 0.95</td>
<td>0.0626</td>
</tr>
<tr>
<td>5</td>
<td>p ≥ 0.95</td>
<td>0.0941</td>
</tr>
<tr>
<td>Repository Average</td>
<td></td>
<td>0.0750</td>
</tr>
</tbody>
</table>

Source: Output DTN: MO0710PLOTSTFIGS.000 [DIRS 185207], file: LA_v5.005_NC_000300_000_Seepage_Fraction.xls.

**NOTE:** The repository average values are based on weighted averages for each realization using the percolation subregion quantile ranges.
Table 8.3-4[a]. Seepage Fractions for CDSP and CSNF Waste Packages for Seismic Ground Motion Modeling Case for Glacial-Transition Climate, 2,000 to 10,000 Years

<table>
<thead>
<tr>
<th>Percolation Subregion</th>
<th>Seepage Fraction for CDSP Waste Packages</th>
<th>Seepage Fraction for CSNF Waste Packages</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5th Percentile</td>
<td>Mean</td>
</tr>
<tr>
<td>1 p &lt; 0.05</td>
<td>0.0031</td>
<td>0.0881</td>
</tr>
<tr>
<td>2 0.05 ≤ p &lt; 0.30</td>
<td>0.0261</td>
<td>0.2292</td>
</tr>
<tr>
<td>3 0.30 ≤ p &lt; 0.70</td>
<td>0.0448</td>
<td>0.3306</td>
</tr>
<tr>
<td>4 0.70 ≤ p &lt; 0.95</td>
<td>0.0453</td>
<td>0.3846</td>
</tr>
<tr>
<td>5 p ≥ 0.95</td>
<td>0.088</td>
<td>0.4656</td>
</tr>
<tr>
<td>Repository Average</td>
<td>0.0441</td>
<td>0.3134</td>
</tr>
</tbody>
</table>

Source: Output DTN: MO0710PLOTSFIGS.000 [DIRS 185207], file: LA_v5.005_SM_009000_001_Seepage_Fraction.xls.

NOTE: The repository average values are based on weighted averages for each realization using the percolation subregion quantile ranges.

Table 8.3-5[a]. Seepage Fractions for CDSP and CSNF Waste Packages for Seismic Ground Motion Modeling Case for Post-10,000-Year Period

<table>
<thead>
<tr>
<th>Percolation Subregion</th>
<th>Seepage Fraction for CDSP Waste Packages</th>
<th>Seepage Fraction for CSNF Waste Packages</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5th Percentile</td>
<td>Mean</td>
</tr>
<tr>
<td>1 p &lt; 0.05</td>
<td>0.3252</td>
<td>0.4666</td>
</tr>
<tr>
<td>2 0.05 ≤ p &lt; 0.30</td>
<td>0.3077</td>
<td>0.6484</td>
</tr>
<tr>
<td>3 0.30 ≤ p &lt; 0.70</td>
<td>0.309</td>
<td>0.7196</td>
</tr>
<tr>
<td>4 0.70 ≤ p &lt; 0.95</td>
<td>0.231</td>
<td>0.7051</td>
</tr>
<tr>
<td>5 p ≥ 0.95</td>
<td>0.3076</td>
<td>0.7525</td>
</tr>
<tr>
<td>Repository Average</td>
<td>0.2909</td>
<td>0.6871</td>
</tr>
</tbody>
</table>

Source: Output DTN: MO0710PLOTSFIGS.000 [DIRS 185207], file: LA_v5.005_SM_009000_003_Seepage_Fraction.xls.

NOTE: The repository average values are based on weighted averages for each realization using the percolation subregion quantile ranges.
Table 8.3-6[a]. Drift Wall Condensation for CSNF Waste Packages for Stage 2 and Stage 3 Condensation

<table>
<thead>
<tr>
<th>Percolation Subregion</th>
<th>CSNF Waste Packages</th>
<th>Stage 2</th>
<th>Stage 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Probability</td>
<td>Mean WP Fraction</td>
<td>Mean Flux (m³/yr)</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Source: Output DTN: MO0801TSPAMVAC.000 [DIRS 185080], file: condensation_rates_and_fractions.xls.

NOTE: Drift-wall condensation fraction and flux are the same for both the combined Nominal/Early Failure and Seismic Ground Motion Modeling Cases.
Table 8.3-7[a]. Drift Wall Condensation for CDSP Waste Packages for Stage 2 and Stage 3 Condensation

<table>
<thead>
<tr>
<th>Percolation Subregion</th>
<th>Probability</th>
<th>WP Fraction</th>
<th>Mean Flux (m³/yr)</th>
<th>Mean Duration</th>
<th>Probability at 1,500 Years</th>
<th>Mean WP Fraction</th>
<th>Mean Flux (m³/yr) at 1,500 Years</th>
<th>Mean Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0.54</td>
<td>0 to 1,000 years</td>
<td>0.020</td>
<td>0.020</td>
<td>6.78E-05</td>
<td>750 to 2,000 years</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>1</td>
<td>0.54</td>
<td>0 to 1,000 years</td>
<td>0.017</td>
<td>0.017</td>
<td>5.97E-05</td>
<td>750 to 2,000 years</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>1</td>
<td>0.54</td>
<td>0 to 1,000 years</td>
<td>0.017</td>
<td>0.017</td>
<td>7.16E-05</td>
<td>750 to 2,000 years</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>1</td>
<td>0.54</td>
<td>0 to 1,000 years</td>
<td>0.0033</td>
<td>0.0033</td>
<td>6.00E-06</td>
<td>750 to 2,000 years</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>1</td>
<td>0.54</td>
<td>0 to 1,000 years</td>
<td>0.010</td>
<td>0.010</td>
<td>4.32E-05</td>
<td>750 to 2,000 years</td>
</tr>
</tbody>
</table>

Source: Output DTN: MO0801TSPAMVAC.000 [DIRS 185080], file: condensation_rates_and_fractions.xls.

NOTE: Drift-wall condensation fraction and flux are the same for both the combined Nominal/Early Failure and Seismic Ground Motion Modeling Cases.

Table 8.3-8[a]. Mean Seepage Rates for Waste Packages during Stage 2 and Stage 3 Condensation

<table>
<thead>
<tr>
<th>Percolation Subregion</th>
<th>Mean Seepage Rates (m³/yr) 0 to 2,000 years (Seepage at 1,500 years)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CNSF Waste Packages</td>
</tr>
<tr>
<td>Subregion Index</td>
<td>Quantile Range</td>
</tr>
<tr>
<td>1</td>
<td>p &lt; 0.05</td>
</tr>
<tr>
<td>2</td>
<td>0.05 ≤ p &lt; 0.30</td>
</tr>
<tr>
<td>3</td>
<td>0.30 ≤ p &lt; 0.70</td>
</tr>
<tr>
<td>4</td>
<td>0.70 ≤ p &lt; 0.95</td>
</tr>
<tr>
<td>5</td>
<td>p ≥ 0.95</td>
</tr>
<tr>
<td>Repository Average</td>
<td></td>
</tr>
</tbody>
</table>

Source: Output DTN: MO0801TSPAMVAC.000 [DIRS 185080], file: condensation_rates_and_fractions.xls.

NOTES: Mean seepage flux is the same for both the Nominal/Early Failure and Seismic Ground Motion Modeling Cases over the first 2,000 years.

The repository average values are weighted averages using the percolation subregion quantile ranges.
8.4[a] VALIDITY AND DEFENSIBILITY OF PERFORMANCE DEMONSTRATION

The validation activities are presented in Section 7 of the parent document and an additional set of analyses are presented in Section 7[a] of this addendum. Any additions to the description of the TSPA-LA Model presented in Section 6 of the parent document are presented in Section 6[a]. The technical basis for the component models and TSPA input database is documented in supporting model reports. The parent document and supporting documentation were prepared in a manner that would ensure the technical basis is auditable and traceable so as to facilitate the licensing review.

The issuance of this addendum reflects the TSPA methodology defined in the parent document, which specifies:

- Continued scrutiny of the conceptual and mathematical models through internal and external peer reviews
- Further development and testing of TSPA component models and submodels
- Statistical analysis of data and development of improved characterizations of uncertainty.

In this addendum, the issues identified in Appendix P of the parent document have been addressed, the rationale for their use explained, and their impact on postclosure performance metrics evaluated.

This section provides a summary of the specific YMP technical and programmatic activities conducted to ensure that the DOE postclosure performance demonstration is suitable to support the LA for the nuclear waste repository at Yucca Mountain. This section has not changed and applies to the work presented in this addendum.

8.4.1[a] Validation of TSPA Model and Component Models

No change.

8.4.2[a] Verification and Validation of TSPA Software and Input Data

No change.

8.4.3[a] Uncertainty Characterization Reviews

No change.

8.4.4[a] Corroboration of TSPA-LA Results

No change.

8.4.5[a] Peer Reviews of YMP TSPA Methodology

No change.
Figure 8.1-1[a]. Distribution of Total Expected Annual Dose for 10,000 Years after Repository Closure

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; MO0710PLOTSFIG.000 [DIRS 185207]; and MO0709TSPAREGS.000 [DIRS 182976].
Figure 8.1-2[a]. Distribution of Total Expected Annual Dose for 1,000,000 Years after Closure

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; MO0710PLOTSFIG.000 [DIRS 185207]; and MO0709TSPAREGS.000 [DIRS 182976].
Figure 8.1-3[a]. Relative Contributions of Modeling Cases to Total Mean Annual Dose for (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752] and MO0709TSPAREGS.000 [DIRS 182976].
Source: Output DTN: MO0710ADTSPAWO.000 [DIRS 183752].

NOTE: Nominal failures are due to general corrosion. Seismic ground motion failures are caused by the combined effects of general corrosion, vibratory ground motion, and rockfall.

Figure 8.1-4[a]. Histogram of the Time of Drip Shield Failure for the Nominal and Seismic Ground Motion Modeling Cases
Figure 8.1-5[a]. Fraction of (a) CDSP Waste Packages and (b) CSNF Waste Packages Failed by Seismic Damage as a Function of Time

Source: Output DTN: MO0801TSPAWPDS.000 [DIRS 185077].
Figure 8.1-6[a]. Contribution of Individual Radionuclides to Total Mean Annual Dose for 10,000 Years after Repository Closure

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; MO0710PLOTSFIG.000 [DIRS 185207]; and MO0709TSPAREGS.000 [DIRS 182976].
Figure 8.1-7[a]. Contribution of Individual Radionuclides to Total Mean Annual Dose for 1,000,000 Years after Repository Closure
Figure 8.1-9[a]. Summary Statistics for Activity Concentrations of Total Radium (\(^{226}\)Ra and \(^{228}\)Ra) in Groundwater, Excluding Natural Background, for 10,000 Years after Repository Closure

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0710PLOTSFIG.000 [DIRS 185207].
Figure 8.1-10[a]. Contributions of the Modeling Cases to the Mean Combined $^{226}$Ra and $^{228}$Ra Activity Concentration in Groundwater, Excluding Natural Background, for 10,000 Years after Repository Closure
Figure 8.1-11[a]. Summary Statistics for Activity Concentration of Gross Alpha and $^{226}$Ra (Excluding Radon and Uranium) in Groundwater for 10,000 Years after Repository Closure
Figure 8.1-12[a]. Contributions of the Modeling Cases to the Mean Gross Alpha Activity Concentrations (Including $^{226}\text{Ra}$ but Excluding Radon and Uranium) in Groundwater for 10,000 Years after Repository Closure.
NOTE: There are 24 dose histories in the plot: 23 organs and one for the whole body.

Figure 8.1-13[a]. Mean Annual Dose from Beta-Photon Dose for All Organs, Including the Whole Body for (a) 10,000 Years after Repository Closure and (b) Detail for 8,000 to 10,000 Years after Repository Closure
Figure 8.1-14[a]. Summary Statistics for Annual Drinking Water Doses for Combined Beta and Photon Emitting Radionuclides for 10,000 Years after Repository Closure
Figure 8.1-15[a]. Contributions of Modeling Cases to the (a) Whole Body Dose and (b) Thyroid for 10,000 Years after Repository Closure

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0710PLOTSFIG.000 [DIRS 185207].
Figure 8.1-16[a]. Distribution of Expected Annual Doses for the Human Intrusion Scenario for 1,000,000 Years after Repository Closure with Drilling Event at 200,000 Years.
Figure 8.1-17[a]. Contribution of Individual Radionuclides to Mean Annual Dose for the Human Intrusion Scenario for 1,000,000 Years after Repository Closure

Source: Output DTN: MO0710ADTSPAWO.000 [DIRS 183752].
Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0710PLOTSFIG.000 [DIRS 185207].

Figure 8.2-1[a]. Distributions of Expected Annual Dose for the Nominal Modeling Case for 1,000,000 Years after Repository Closure
Figure 8.2-2[a]. Contribution of Individual Radionuclides to Mean Annual Dose for the Nominal Modeling Case for 1,000,000 Years after Repository Closure.
Figure 8.2-3(a). Distributions of Expected Annual Dose for the Drip Shield Early Failure Modeling Case for (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure.

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0710PLOTSFIG.000 [DIRS 185207].
Figure 8.2-4[a]. Contribution of Individual Radionuclides to Mean Annual Dose for Drip Shield Early Failure Modeling Case for (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0710PLOTFIG.000 [DIRS 185207].
Figure 8.2-5[a]. Distributions of Expected Annual Dose for Waste Package Early Failure Modeling Case for (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0710PLOTSTFIG.000 [DIRS 185207].
Figure 8.2-6[a]. Contribution of Individual Radionuclides to Mean Annual Dose for Waste Package Early Failure Modeling Case for (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0710PLOTSFIG.000 [DIRS 185207].
Figure 8.2-7[a]. Distributions of Expected Annual Dose for the Igneous Intrusion Modeling Case for (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0710PLOTSFIG.000 [DIRS 185207].
Figure 8.2-8[a]. Contribution of Individual Radionuclides to Mean Annual Dose for the Igneous Intrusion Modeling Case for (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0710PLOTSFIG.000 [DIRS 185207].
Figure 8.2-11[a]. Distributions of Expected Annual Dose for the Seismic Ground Motion Modeling Case for (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0710PLOTSFIG.000 [DIRS 185207].
Figure 8.2-12[a]. Contribution of Individual Radionuclides to Mean Annual Dose for the Seismic Ground Motion Modeling Case for (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0710PLOTFIG.000 [DIRS 185207].
Figure 8.2-13[a]. Distributions of Expected Annual Dose for the Seismic Fault Displacement Modeling Case for (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0710PLOTSFIG.000 [DIRS 185207].
Figure 8.2-14[a]. Contribution of Individual Radionuclides to Mean Annual Dose for the Seismic Fault Displacement Modeling Case for (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure
Figure 8.3-1[a]. Mean Radionuclide Activities for Total Repository Inventory as a Function of Time for (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0710PLOTSFIG.000 [DIRS 185207].
Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0710PLOTSFIG.000 [DIRS 185207].

Figure 8.3-2[a]. Mean Radionuclide Contributions to Total Inventory as a Function of Time for (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure
Total System Performance Assessment Model/Analysis for the License Application

NOTE: For comparison to seepage, volumetric fluxes (m$^3$/yr) of infiltration and post-10,000 year percolation are calculated by multiplying the net infiltration and post-10,000 year percolation rates by the plan area over an intact drift (m$^2$).

**Figure 8.3-3[a].** Upper Natural Barrier Capability to Prevent or Substantially Reduce the Rate of Water Movement to the Waste for the Mean Spatially-Averaged (a) Annual Precipitation, Net Infiltration, and Post-10,000-Year Percolation Rates and (b) Drift Seepage Fluxes for the Combined Nominal/Early Failure Modeling Case and the Seismic Ground Motion Modeling Case – 1,000,000-Year Period

Source: SNL 2007 [DIRS 182145], Tables 6.5.7.1-3, 6.5.7.2-3, and 6.5.7.3-3; NRC Proposed Rule 10 CFR 63.342(c)(2) [DIRS 178394]; and Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; MO0710PLOTSFIG.000 [DIRS 185207].
Source: Output DTNs: MO0801TSPAWPDS.000 [DIRS 185077]; and MO0710PLOTSFIG.000 [DIRS 185207].

Figure 8.3-4[a]. Probability of Drip Shield Failure by General Corrosion for the Nominal Modeling Case Based on 300 Epistemic Realizations of Drip Shield General Corrosion Rates
Figure 8.3-5[a]. Summary Statistics for Fraction of Waste Packages Breached for (a) CSNF Waste Packages and (b) CDSP Waste Packages for the Nominal Modeling Case as a Function of Time
Figure 8.3-6[a]. Summary Statistics for Fraction of CSNF Waste Packages (a) Breached by Stress Corrosion Cracking and (b) Breached by General Corrosion Patches for the Nominal Modeling Case as a Function of Time
Figure 8.3-7[a]. Cumulative Distribution Functions of Drip Shield Failure Time for (a) Distributions of Failure Time for 300 Epistemic Sample Elements and (b) Distribution of Expected (Over Aleatory) Failure Time with Confidence Interval for the Seismic Ground Motion Modeling Case.

Source: Output DTN: MO0710ADTSPAWO.000 [DIRS 183752].
Summary Statistics for Expected Fraction of CSNF WPs (a) Breached by Seismic and Nominal Processes and (b) Breached by Seismic Processes Only; and CDSP WPs (c) Breached by Seismic and Nominal Processes and (d) Breached by Seismic Processes Only for the Seismic Ground Motion Modeling Case as a Function of Time.

Source: Output DTN: MO0801TSPA WPDS.000 [DIRS 185077].
Figure 8.3-8[a]. Summary Statistics for Expected Fraction of CSNF WPs (a) Breached by Seismic and Nominal Processes and (b) Breached by Seismic Processes Only; and CDSP WPs (c) Breached by Seismic and Nominal Processes and (d) Breached by Seismic Processes Only for the Seismic Ground Motion Modeling Case as a Function of Time (continued)
Figure 8.3-9[a]. Summary Statistics for Average Fraction of CSNF Waste Package Surface Breached by Cracks per Breached Waste Package for (a) the Seismic Ground Motion Modeling Case and (b) the Nominal Modeling Case as a Function of Time.
Figure 8.3-10[a]. Summary Statistics for Fraction of CDSP Waste Package Surface Breached by Cracks per Breached Waste Package for (a) the Seismic Ground Motion Modeling Case and (b) the Nominal Modeling Case as a Function of Time.
Figure 8.3-11[a]. Summary Statistics for Fraction of CSNF Waste Package Surface Breached by Patches per Breached Waste Package for (a) the Seismic Ground Motion Modeling Case and (b) the Nominal Modeling Case as a Function of Time
Figure 8.3-12[a]. Summary Statistics for Fraction of CDSP WP Surface Breached by Patches per Breached Waste Package for (a) the Seismic Ground Motion Modeling Case and (b) the Nominal Modeling Case as a Function of Time.

Source: Output DTN: MO0801TSPAWPDS.000 [DIRS 185077].
Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0710PLOTSFIG.000 [DIRS 185207].

NOTE: Total inventory indicates the repository total activity as a function of time and is included for comparison to the activity released.

Figure 8.3-13[a]. Mean Activity Released from the Engineered Barrier System for the Combined Nominal/Early Failure Modeling Case for (a) 10,000 Years after Repository Closure and (b) Post-10,000-Years after Repository Closure
NOTE: Mean total inventory indicates the repository total $^{99}$Tc activity as a function of time and is included for comparison to the activity released.

Figure 8.3-14[a]. Uncertainty in Activity of $^{99}$Tc Released from the Engineered Barrier System for the Combined Nominal/Early Failure Modeling Case for (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure
NOTE: Mean total inventory indicates the repository total $^{239}$Pu activity as a function of time and is included for comparison to the activity released.

Figure 8.3-15[a]. Uncertainty in Activity of $^{239}$Pu Released from the Engineered Barrier System for the Combined Nominal/Early Failure Modeling Case for (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure
NOTE: Total inventory indicates the repository total activity as a function of time and is included for comparison to the activity released.

Figure 8.3-16[a]. Mean Activity Released from the Engineered Barrier System for the Seismic Ground Motion Modeling Case for (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure
Figure 8.3-17[a]. Uncertainty in Activity of $^{99}$Tc Released from the Engineered Barrier System for the Seismic Ground Motion Modeling Case for (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0710PLOTSFIG.000 [DIRS 185207].

NOTE: Mean total inventory indicates the repository total $^{99}$Tc activity as a function of time and is included for comparison to the activity released.

Mean total inventory indicates the repository total $^{99}$Tc activity as a function of time and is included for comparison to the activity released.
NOTE: Mean total inventory indicates the repository total $^{237}\text{Np}$ activity as a function of time and is included for comparison to the activity released.

Figure 8.3-18[a]. Uncertainty in Activity of $^{237}\text{Np}$ Released from the Engineered Barrier System for the Seismic Ground Motion Modeling Case for (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure
NOTE: Mean total inventory indicates the repository total $^{234}\text{U}$ activity as a function of time and is included for comparison to the activity released.

Figure 8.3-19[a]. Uncertainty in Activity of $^{234}\text{U}$ Released from the Engineered Barrier System for the Seismic Ground Motion Modeling Case for (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure
NOTE: Mean total inventory indicates the repository total $^{226}$Ra activity as a function of time and is included for comparison to the activity released.

Figure 8.3-20[a]. Uncertainty in Activity of $^{226}$Ra Released from the Engineered Barrier System for the Seismic Ground Motion Modeling Case for (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure.
NOTE: Mean total inventory indicates the repository total $^{239}$Pu activity as a function of time and is included for comparison to the activity released.

Figure 8.3-21[a]. Uncertainty in Activity of $^{239}$Pu Released from the Engineered Barrier System for the Seismic Ground Motion Modeling Case for (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure
NOTE: Mean total inventory indicates the repository total $^{242}$Pu activity as a function of time and is included for comparison to the activity released.

Figure 8.3-22[a]. Uncertainty in Activity of $^{242}$Pu Released from the Engineered Barrier System for the Seismic Ground Motion Modeling Case for (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure
Total System Performance Assessment Model/Analysis for the License Application

NOTE: Total inventory indicates the repository total activity as a function of time and is included for comparison to the activity released.

Figure 8.3-23[a]. Mean Activity Released from the (a) Saturated Zone and (b) Engineered Barrier System for the Combined Nominal/Early Failure Modeling Case for 10,000 Years after Repository Closure

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0710PLOTSFIG.000 [DIRS 185207].
Total System Performance Assessment Model/Analysis for the License Application

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0710PLOTSFIG.000 [DIRS 185207].

NOTE: Total inventory indicates the repository total activity as a function of time and is included for comparison to the activity released.

Figure 8.3-24[a]. Mean Activity Released from the (a) Saturated Zone and (b) Engineered Barrier System for the Combined Nominal/Early Failure Modeling Case for 1,000,000 Years after Repository Closure
Figure 8.3-25[a]. Mean Activity Released from the (a) Saturated Zone and (b) Engineered Barrier System for the Seismic Ground Motion Modeling Case for 10,000 Years after Repository Closure

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0710PLOTSFIG.000 [DIRS 185207].

NOTE: Total inventory indicates the repository total activity as a function of time and is included for comparison to the activity released.
NOTE: Total inventory indicates the repository total activity as a function of time and is included for comparison to the activity released.

Figure 8.3-26[a]. Mean Activity Released from the (a) Saturated Zone and (b) Engineered Barrier System for the Seismic Ground Motion Modeling Case for 1,000,000 Years after Repository Closure.

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0710PLOTSFIG.000 [DIRS 185207].
NOTE: Mean total inventory indicates the repository total $^{99}$Tc activity as a function of time and is included for comparison to the activity released.

Figure 8.3-27[a]. Uncertainty in Activity of $^{99}$Tc Released from the Saturated Zone for the Seismic Ground Motion Modeling Case for (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure
NOTE: Mean total inventory indicates the repository total $^{237}$Np activity as a function of time and is included for comparison to the activity released.

Figure 8.3-28[a]. Uncertainty in Activity of $^{237}$Np Released from the Saturated Zone for the Seismic Ground Motion Modeling Case for (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure.
Figure 8.3-29[a]. Uncertainty in Activity of $^{234}$U Released from the Saturated Zone for the Seismic Ground Motion Modeling Case for (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure

Source: Output DTN: MO0710ADTSPAWO.000 [DIRS 183752].

NOTE: Mean total inventory indicates the repository total $^{234}$U activity as a function of time and is included for comparison to the activity released.
NOTE: Mean total inventory indicates the repository total $^{226}\text{Ra}$ activity as a function of time and is included for comparison to the activity released.

Figure 8.3-30[a]. Uncertainty in Activity of $^{226}\text{Ra}$ Released from the Saturated Zone for the Seismic Ground Motion Modeling Case for (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure.
NOTE: Mean total inventory indicates the repository total $^{239}$Pu activity as a function of time and is included for comparison to the activity released.

Figure 8.3-31[a]. Uncertainty in Activity of $^{239}$Pu Released from the Saturated Zone for the Seismic Ground Motion Modeling Case for (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure
NOTE: Mean total inventory indicates the repository total $^{242}$Pu activity as a function of time and is included for comparison to the activity released.

Figure 8.3-32[a]. Uncertainty in Activity of $^{242}$Pu Released from the Saturated Zone for the Seismic Ground Motion Modeling Case for (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure
9[a]. INPUTS AND REFERENCES

9.1[a] DOCUMENTS CITED


<table>
<thead>
<tr>
<th>Document ID</th>
<th>Title</th>
<th>Author</th>
<th>Place</th>
<th>ACC</th>
</tr>
</thead>
</table>
9.2[a] CODES, STANDARDS, REGULATIONS, AND PROCEDURES


156671 66 FR 55732. Disposal of High-Level Radioactive Wastes in a Proposed Geologic Repository at Yucca Mountain, NV, Final Rule. 10 CFR Parts 2, 19, 20, 21, 30, 40, 51, 60, 61, 63, 70, 72, 73, and 75. ACC: MOL.20050324.0102; MOL.20050418.0124.

177357 70 FR 49014. Public Health and Environmental Radiation Protection Standards for Yucca Mountain, NV. Internet Accessible.

178394 70 FR 53313. Implementation of a Dose Standard After 10,000 Years. Internet Accessible.


9.3[a] SOFTWARE CODES


<table>
<thead>
<tr>
<th>Reference</th>
<th>Version</th>
<th>Date</th>
<th>Operating Systems</th>
<th>STN</th>
</tr>
</thead>
<tbody>
<tr>
<td>180002</td>
<td>FAR V. 1.1</td>
<td>2007</td>
<td>WINDOWS 2000 &amp; 2003</td>
<td>11190-1.1-00</td>
</tr>
<tr>
<td>182225</td>
<td>FAR V. 1.2</td>
<td>2007</td>
<td>WINDOWS 2000 &amp; WINDOWS 2003</td>
<td>11190-1.2-00</td>
</tr>
<tr>
<td>173139</td>
<td>FEHM V. 2.23</td>
<td>2005</td>
<td>WINDOWS 2000</td>
<td>10086-2.23-00</td>
</tr>
<tr>
<td>179419</td>
<td>FEHM V. 2.24-01</td>
<td>2007</td>
<td>WIN2003, 2000, &amp; XP, Red Hat Linux 2.4.21, OS 5.9</td>
<td>10086-2.24-01-00</td>
</tr>
<tr>
<td>181040</td>
<td>GetThk_LA V. 1.0</td>
<td>2006</td>
<td>WINDOWS 2000 &amp; WINDOWS 2003</td>
<td>11229-1.0-00</td>
</tr>
<tr>
<td>180224</td>
<td>GoldSim V. 9.60</td>
<td>2007</td>
<td>WINDOWS 2000, WINDOWS XP, WINDOWS 2003</td>
<td>10344-9.60-00</td>
</tr>
<tr>
<td>167885</td>
<td>InterpZdll_LA V. 1.0</td>
<td>2004</td>
<td>WINDOWS 2000</td>
<td>11107-1.0-00</td>
</tr>
<tr>
<td>181043</td>
<td>InterpZdll_LA V. 1.0</td>
<td>2007</td>
<td>WINDOWS 2003</td>
<td>11107-1.0-01</td>
</tr>
<tr>
<td>167884</td>
<td>MFCP_LA V. 1.0</td>
<td>2003</td>
<td>WINDOWS 2000</td>
<td>11071-1.0-00</td>
</tr>
<tr>
<td>181045</td>
<td>MFCP_LA V. 1.0</td>
<td>2006</td>
<td>WINDOWS 2003</td>
<td>11071-1.0-01</td>
</tr>
<tr>
<td>174528</td>
<td>MkTable V. 1.00</td>
<td>2003</td>
<td>WINDOWS 2000</td>
<td>10505-1.00-00</td>
</tr>
<tr>
<td>181047</td>
<td>Mkable_LA V. 1.0</td>
<td>2006</td>
<td>WINDOWS 2000</td>
<td>11217-1.0-00</td>
</tr>
<tr>
<td>181048</td>
<td>MkTable_LA V. 1.0</td>
<td>2007</td>
<td>WINDOWS 2003</td>
<td>11217-1.0-01</td>
</tr>
<tr>
<td>181049</td>
<td>MView V. 4.0</td>
<td>2007</td>
<td>WINDOWS XP</td>
<td>10072-4.0-01</td>
</tr>
<tr>
<td>169130</td>
<td>PassTable1D_LA V. 1.0</td>
<td>2004</td>
<td>WINDOWS 2000</td>
<td>11142-1.0-00</td>
</tr>
<tr>
<td>181050</td>
<td>PassTable1D_LA V. 1.0</td>
<td>2006</td>
<td>WINDOWS 2003</td>
<td>11142-1.0-01</td>
</tr>
<tr>
<td>181051</td>
<td>PassTable1D_LA V. 2.0</td>
<td>2007</td>
<td>WINDOWS 2000 &amp; WINDOWS 2003</td>
<td>11142-2.0-00</td>
</tr>
<tr>
<td>168980</td>
<td>PassTable3D_LA V. 1.0</td>
<td>2004</td>
<td>WINDOWS 2000</td>
<td>11143-1.0-00</td>
</tr>
<tr>
<td>181052</td>
<td>PassTable3D_LA V. 1.0</td>
<td>2007</td>
<td>WINDOWS 2003</td>
<td>11143-1.0-01</td>
</tr>
<tr>
<td>182556</td>
<td>PassTable3D_LA V. 2.0</td>
<td>2007</td>
<td>WINDOWS 2000 &amp; WINDOWS 2003</td>
<td>11143-2.0-00</td>
</tr>
</tbody>
</table>
181157  SCCD V. 2.01. 2003. WINDOWS 2000. STN: 10343-2.01-00.
181054  SCCD V. 2.01. 2007. WINDOWS 2003. STN: 10343-2.01-01.
180318  SEEPAGEDLL_LA V. 1.3. 2006. WINDOWS 2000. STN: 11076-1.3-00.
181058  SEEPAGEDLL_LA V. 1.3. 2007. WINDOWS 2003. STN: 11076-1.3-01.
161256  Software Code: TOUGHREACT V. 3.0. 2002. DEC ALPHA/OSF1 V5.1, DEC
         ALPHA/OSF1 V5.0, Sun UltraSparc/Sun OS 5.5.1, PC/Linux Redhat 7.2. STN:
         10396-3.0-00.
181060  SZ_CONVOLUTE V. 3.10.01. 2007. WINDOWS 2000 & WINDOWS 2003. STN:
         10207-3.10.01-00.
146654  T2R3D V. 1.4. 1999. UNIX, WINDOWS 95/98NT 4.0. STN: 10006-1.4-00.
161491  TOUGH2 V. 1.6. 2003. DOS Emulation (win95/98), SUN OS 5.5.1., OSF1 V4.0.
         STN: 10007-1.6-01.
181061  TSPA_Input_DB V. 2.2. 2006. WINDOWS 2000. STN: 10931-2.2-00.
181062  TSPA_Input_DB V. 2.2. 2006. WINDOWS 2003. STN: 10931-2.2-01.

9.4[a]  SOURCE DATA LISTED BY DATA TRACKING NUMBER

171584  LA0408AM831341.001. Unsaturated Zone Distribution Coefficients (Kds) for U,
         Np, Pu, Am, Pa, Cs, Sr, Ra, and Th. Submittal date: 08/24/2004.
180497  LA0701PANS02BR.003. UZ Transport Parameters. Submittal date: 04/23/2007.
180322  LA0702PANS02BR.001. Repository and Water Table Bins. Submittal date:
         04/16/2007.
179299  LB0701PAKDSESN.001. Unsaturated Zone Sorption Coefficients for Selenium and
         Tin. Submittal date: 01/31/2007.

180776  LB0702PAUZMTDF.001. Unsaturated Zone Matrix Diffusion Coefficients. Submittal date: 05/10/2007.

180439  MO0701PACSNFCP.000. CSNF Colloid Parameters. Submittal date: 04/17/2007.


181219  MO0702PAFLUORI.000. Fluoride Uncertainty Associated with Dissolved Concentration Limits. Submittal date: 06/01/2007.


184647  MO0704PAFEHMBR.001. FEHM Model and Input. Submittal date: 01/10/2008.

185200  MO0706SPAFEPLA.001. FY 2007 LA FEP List and Screening. Submittal date: 03/05/2008.


168761  SN0310T0505503.004. Initial Radionuclide Inventories for TSPA-LA. Submittal date: 10/27/2003.


182961  SN0701PAWPHIT1.001. Number of Waste Packages Hit by Igneous Events. Submittal date: 09/13/2007.

179504  SN0702PASZFTMA.001. Saturated Zone Flow and Transport Model Abstraction. Submittal date: 02/06/2007.

<table>
<thead>
<tr>
<th>Document ID</th>
<th>Description</th>
<th>Submittal Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>SN0703PAEBRTA.001</td>
<td>Inputs Used in the Engineered Barrier System (EBS) Radionuclide Transport Abstraction.</td>
<td>09/28/2007</td>
</tr>
<tr>
<td>SN0704PADSGCMT.001</td>
<td>Drip Shield General Corrosion Models Based on 2.5-Year Titanium Grade 7 Corrosion Rates.</td>
<td>07/24/2007</td>
</tr>
<tr>
<td>SN0710PASZFTMA.003</td>
<td>Updated Saturated Zone 1-D Transport Model.</td>
<td>10/10/2007</td>
</tr>
</tbody>
</table>
APPENDIX B\[a]\nDATA TRACKING NUMBERS FOR THE TSPA-LA MODEL
B1[a] INTRODUCTION

Appendix B of the parent document describes the interrelationships among the Total System Performance Assessment for the License Application (TSPA-LA) Model output data tracking numbers (DTNs) for the TSPA-LA Model. Additional output generated as a result of the analysis presented in this addendum is described in Appendix B[a]. Figure B-3[a] shows the information flow among the output DTNs submitted to the Technical Data Management System for the analyses documented in this addendum.

The following sections contain brief descriptions of the contents of the DTNs. The respective ReadMe.doc file located in each DTN provides more detailed information on the contents of each DTN. Figure B-3[a] provides an overview of the relationships between the DTNs.

B2[a] DESCRIPTIONS OF THE DATA TRACKING NUMBERS

The following text supports Figure B-3[a]. Figures B-1 and B-2 in the parent document remain unchanged and are documented in Appendix B, Section B.2, of the parent document.

B2.1[a] MODEL DEVELOPMENT RECORDS PACKAGE

This records package documents each of the model changes that were generated since v5.000 of the Model. This records package contains v5.001 through v5.005 of the Groundwater Model. All model versions generally follow the same folder content. For example, the content for a typical folder would contain a Master Folder and the specific case folders that were appropriate at that stage of model development. Each Master Folder generally contains the following:

- One or more change approval forms
- Change checklist
- Implementation checklist
- Conceptual checklist
- Conceptual description
- GoldSim model file
- GoldSim version report
- Additional information directory (optional).

This records package feeds output DTN: MO0710ADTSPAWO.000_R0 [DIRS 183752], which utilizes the final version of the Groundwater Model (v5.005).

B2.2[a] PLOTS AND FIGURES FOR THE TSPA-LA ADDENDUM (V5.005): OUTPUT DTN: MO0710PLOTSFIG.000_R1 [DIRS 185207]

Reference Figure B-3[a], Block 4—This DTN contains electronic copies of the plots and any post-processing files for all of the plots generated for this document. The plots were generated using SigmaPlot 2002 for Windows Version 8.0, (www.sigmaplot.com). Each figure generated for this document includes header information listing the file name(s) which contain the output data used in the plot (generally a GoldSim file with the file extension .gsm) which can be found in the source DTN listed for the plot. The plot header information contains the file name(s) of the SigmaPlot (file extension .JNB) and any post-processing files used to generate the plot which
can be found in this DTN. In addition, any checklists used for checking of the plots are also included.

**B2.3[a]** **TSPA-LA ADDENDUM PARAMETER SENSITIVITY ANALYSIS: OUTPUT DTN: MO0801TSPAPRSA.000_R0 [DIRS 184620]**

Reference Figure B-3[a], Block 6—This DTN contains analyses to evaluate the significant uncertain parameters in the TSPA-LA Groundwater Models that are documented in output DTN: MO0710ADTSPAWO.000_R0 [DIRS 183752].

**B2.4[a]** **TSPA-LA ADDENDUM, REPRESENTATION OF (GW V5.005) NAVAL SPENT NUCLEAR FUEL: OUTPUT DTN: MO0801TSPANSNF.000_R0 [DIRS 184619]**

Reference Figure B-3[a], Block 5—This DTN contains the TSPA-LA Model cases, including checking documentation, that were run to evaluate the representation of naval spent nuclear fuel in the TSPA-LA Model as discussed in Section 7.5.3[a].

**B2.5[a]** **TSPA-LA ADDENDUM GROUNDWATER MODEL (V5.005) AND ERUPTIVE MODEL (V1.004) WITH FINAL DOCUMENTATION: OUTPUT DTN: MO0710ADTSPAWI.000_R0 [DIRS 183751]**

Reference Figure B-3[a], Block 10—This is the version of the TSPA-LA Groundwater Model (v5.005) and Eruptive Model (v1.004) that is used to generate the GoldSim Player Files that support the TSPA-LA. The difference between the GoldSim files in this DTN versus output DTN: MO0710ADTSPAWO.000_R0 [DIRS 183752] is that this DTN contains the master file for v5.005 and for v1.004. These master files have been modified to update the explanatory text. The explanatory text that is in output DTN: MO0710ADTSPAWO.000_R0 [DIRS 183752] is not as detailed as the explanatory text included in this DTN. The enclosed master files have not been run; therefore, there are no results in this DTN. The value in providing an input file without the output is that the files can be opened on most current model personal computers. The value in adding the documentation is that an interested party can read the embedded text to obtain an overview of how the model is constructed. Also included is a data only copy of the TSPA Input Database. The value of the data-only version of the TSPA Input Database is that an interested party can review the input parameters to quickly determine the numerical value of a parameter as well as the product that the value is documented within. In most cases, the product is an output DTN from a model and/or analysis report.

**B2.6[a]** **TSPA GENERATED INPUTS AND POST-PROCESSED INPUTS: OUTPUT DTN: MO0711GENERINP.000_R0 [DIRS 183937]**

Reference Figure B-3[a], Block 2—This DTN contains inputs that fall into two categories: (1) TSPA-LA Model-generated inputs and (2) post-processed inputs. The TSPA-LA Model generated inputs do not have any external inputs used to create the input values. Post-processed inputs have external inputs supplied by supporting analysis and/or model reports. These external inputs must be post-processed for use in the TSPA-LA Model.
B2.7[a] TSPA-LA ADDENDUM GROUNDWATER MODELING CASES (V5.005) WITHOUT FINAL DOCUMENTATION (USED FOR REGULATORY COMPLIANCE): OUTPUT DTN: MO0710ADTSPAWO.000_R0 [DIRS 183752]

Reference Figure B-3[a], Block 3—This is the version of the Groundwater Model (v5.005) that is used for Regulatory Compliance presented in Section 8[a]. This DTN contains all the modeling cases and supporting checking documentation.

B2.8[a] TSPA-LA ADDENDUM, WASTE PACKAGE AND DRIP SHIELD DEGRADATION ANALYSIS: OUTPUT DTN: MO0801TSPAWPDS.000_R1 [DIRS 185077]

Reference Figure B-3[a], Block 9—This DTN contains the TSPA-LA Waste Package (WP) and Drip Shield (DS) degradation stand alone analysis documented in Section 8.3[a].

B2.9[a] TSPA-LA MODEL (GROUNDWATER) USED FOR REGULATORY COMPLIANCE STABILITY ANALYSIS: OUTPUT DTN: MO0801TSPAADSA.000_R1 [DIRS 185078]

Reference Figure B-3[a], Block 7—This DTN contains the GoldSim runs confirming that the TSPA-LA Model is statistically stable as discussed in Section 7.3.1[a].

B2.10[a] TSPA-LA ADDENDUM, MODEL VALIDATION AND ANALYSES CASES: OUTPUT DTN: MO0801TSPAMVAC.000_R1 [DIRS 185080]

Reference Figure B-3[a], Block 8—This DTN contains GoldSim files addressing the following subjects that support model validation:

- Single Realizations (discussed in Section 7.7.1[a])
- Accuracy of Expected Dose (discussed in Section 7.3.2[a])
- Validation of the Number of Human Intrusion Scenario Timesteps (discussed in Section 7.3.3[a]).


Reference Figure B-3[a], Block 11—This DTN contains the extracted seepage rates and seepage fractions. The results are taken from model development v5.005_GS_9.60.300 of the TSPA-LA Model for one-million years for the Seismic Fault Displacement and Igneous Intrusion Modeling Cases.
Figure B-3[a]. Road Map of TSPA-LA Model v5.005 Data Tracking Numbers
INTENTIONALLY LEFT BLANK
APPENDIX C[a]
PERFORMANCE MARGIN ANALYSIS
C1[a] PURPOSE AND OBJECTIVE

Appendix C of the parent document includes the analyses and results supporting the Performance Margin Analysis (PMA). This addendum documents an additional impact analysis of a single issue identified in the performance margin model implementation that was not previously documented in Section C9 of the parent document. Table C9-1 of the parent document is included as Table C9-1[a] of this addendum. The items numbered 1 through 14 in the table are repeated from the parent document, only the last item (item #15) has been added in this addendum.

C2[a] QUALITY ASSURANCE

No change.

C3[a] USE OF SOFTWARE

No change.

C4[a] INPUTS

No change.

C5[a] ASSUMPTIONS

No change.

C6[a] PERFORMANCE MARGIN ANALYSIS DESCRIPTION

No change, except for the following subsection, C6.3.1[a].

C6.1[a] METHODOLOGY

No change.

C6.2[a] DRIFT-SCALE UNSATURATED ZONE FLOW

No change.

C6.3[a] WASTE PACKAGE AND DRIP SHIELD DEGRADATION

No change.

C6.3.1[a] CONCEPTUAL MODEL

The following paragraphs are edited to correct the value for the WP surface area, and replace the corresponding paragraphs in the parent document.
Localized Corrosion WP Failure Area

Localized corrosion is a phenomenon in which corrosion progresses at discrete sites or in a non-uniform manner (SNL 2007 [DIRS 178519], Section 6.4.4). The area of the Alloy 22 WP outer barrier that is contacted by seepage is potentially subject to localized corrosion (SNL 2007 [DIRS 178519], Sections 6.3.5 and 6.4.4.8.3). In the TSPA-LA Model, it is assumed the maximum available area for localized corrosion (i.e., the area of the WP wetted by seepage) is the area of the WP damaged by localized corrosion (SNL 2007 [DIRS 178519], Section 6.3.5.2.2). Therefore, the entire surface area of the WP is removed as a barrier to water inflow and transport of radionuclides from a localized corrosion damaged WP.

In the PMA, the results of an ACM are used to establish a minimum WP area subject to crevice corrosion processes from localized corrosion (SNL 2007 [DIRS 178519], Section 6.4.4.8.3). The ACM considers a minimum WP creviced surface area based on the WP-to-emplacement pallet contact area (SNL 2007 [DIRS 178519], Sections 6.4.4.8.3). The calculated minimum WP-pallet contact area is $1.924 \times 10^4$ mm$^2$ (SNL 2007 [DIRS 178519], Section 6.4.4.8.3). Therefore, the minimum creviced area is about 0.05 percent of the cylindrical WP surface area of 33 m$^2$ for the transportation, aging, and disposal (TAD) canister-bearing WP configuration. The maximum available area for localized corrosion is the area of the WP wetted by seepage. In the absence of specific information regarding local environments on the WP, for the PMA the area of the WP failed by localized corrosion was assumed to have a log-uniform distribution that was sampled between the range of the entire WP surface area that is exposed to seepage (100 percent) and the calculated ACM minimum of 0.05 percent of the WP surface area (SNL 2007 [DIRS 178519], Section 6.4.4.8.3).

C7[a] RESULTS

No change.

C7.1[a] PERFORMANCE MARGIN IN TOTAL ANNUAL DOSE PREDICTIONS

No change.

C7.2[a] PERFORMANCE MARGIN ANALYSIS—MODELING CASE RESULTS

No change.

C7.3[a] KEY FACTORS AFFECTING THE PERFORMANCE MARGIN

No change.

C8[a] SUMMARY

No change.

C9[a] IMPACT ANALYSIS

Table C9-1 has been updated to include one additional issue (#15) identified during completion of the addendum.
<table>
<thead>
<tr>
<th>ISSUE DESCRIPTION</th>
<th>IMPACT ASSESSMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Fifteen of the sixteen UZ_Params_Multi_PMA tables, input files to FEHM DLL (version 2.25), need to be populated at run time according to the model simulation specific settings.</td>
<td>This issue does not impact the TSPA-LA PMA dose calculation which uses the appropriate updated UZ_Params file for 300 epistemic realizations. The UZ_Params_Multi files, tables of sampled values of epistemically uncertain parameters, are only used when the PMA model is run with the compliance implementation of the unsaturated zone.</td>
</tr>
<tr>
<td>2 The 4 external FEHM .mptr input files need to be updated to point to the correct UZ_Params_Multi_PMA file to use.</td>
<td>This modification only impacts EF EXDOC PMA simulations that turn the PMA UZ implementation off (i.e., compliance UZ implementation is used). This feature was not used for the PMA dose calculations, but was intended for future sensitivity analyses. This change needs to occur in conjunction with populating the UZ_Params_Mult files identified in issue #1. This issue does not have any impact on dose results.</td>
</tr>
<tr>
<td>3 The selector containing the logic for the determination of the CDSP WP Seismic first damage time is incorrectly set.</td>
<td>The first switch in the selector element, Seismic_1st_Dam_Time_CDSP is incorrectly set to suppress any seismic events. The correct setting should select the EXDOC table, Seismic_Time_A1_Spec, which specifies the sampling configuration for the Seismic GM 10,000-year simulation. This issue, which only applies to the 10,000-year Seismic GM simulation, was corrected prior to running the model, and therefore has no impact on dose.</td>
</tr>
<tr>
<td>4 UZ tortuosity parameters, UZ_Tortuosity_RG2_a and UZ_Tortuosity_RG3_a were incorrectly set (v10.002)</td>
<td>The UZ tortuosity parameters should Correct settings: min(1.0,(10^(UZDC_Mean_RG2+UZDC_STN_RG2<em>UZDC_SD_RG2))) The expression for UZ_Tortuosity_RG3_a should be min(1.0,(10^(UZDC_Mean_RG3+UZDC_STN_RG3</em>UZDC_SD_RG3))) This error should have negligible or no impact in all modeling cases.</td>
</tr>
<tr>
<td>5 The IWPD submodel selector elements for the timing of the first Igneous or Seismic event are incorrectly set to suppress events until 400,000 years. To correct this, the first two switches in the selector elements, Event_Time_Feed_IWPD_CDSP and Event_Time_Feed_IWPD_CSNF need to be deleted.</td>
<td>This issue is scenario specific to the Igneous, Seismic FD, and Seismic GM 10,000-year simulations, as well as the Seismic FD 1, 000,000 year simulations. The model file for each of the affected cases was corrected prior to running the file, and therefore does not impact the dose calculations.</td>
</tr>
<tr>
<td>6 ExDoc type runs for both 1Myr EF cases are run with the PMA cladding failure submodel calculations turned on.</td>
<td>This is not an error and is not applicable to the impact evaluation.</td>
</tr>
<tr>
<td>7 The RH threshold for the fluoride ion calculation is incorrect in nineteen of the tables.</td>
<td>Most of these incorrect values were not used in the actual simulations because these values, both the incorrect and the corrected ones, are low (&lt;0.65). At such low RH, the temperatures in the drift will be still high (&gt;96°C) and there will be no seepage water dripping. For the other incorrect values, the differences between the incorrect and the correct ones are small (&lt;0.012). Therefore, the impact on dose is expected to be negligible.</td>
</tr>
<tr>
<td>ISSUE DESCRIPTION</td>
<td>IMPACT ASSESSMENT</td>
</tr>
<tr>
<td>-------------------</td>
<td>-------------------</td>
</tr>
<tr>
<td>8</td>
<td>The PMA early failure scenarios distribute the EBS mass released to the UZ nodes unevenly within a given percolation subregion. Although the EBS mass released to the UZ nodes is distributed unevenly within a given percolation subregion in each realization, the even distribution is captured by calculating the annual mean dose from 300 realizations sampling uncertainty uniformly. Therefore no dose impact is expected.</td>
</tr>
<tr>
<td>9</td>
<td>Certain parameters within the model were not connected to the PMA database. The PMA simulations use the correct values for the parameters listed below, and therefore this issue does not affect the dose calculations. The parameters that need to be linked to the PMA database include, FPLRZN, FPLRZS, FPLRZE, FPVO_PMA, Rf1-Rf10, Kd_Np_RZ, Kd_Np_RZ, SZ_Block_Length, SZ_Block_Thickness, Viscosity_water_T, Sat_Vap_Density_Outside_WP, Water_Vap_Diff_Coeff, Water_Vap_Diff_Cond, Air_Entry_Potential, Sat_Vap_Density_Inside_WP, Osmotic_Coeff, pH_eq</td>
</tr>
<tr>
<td>10</td>
<td>Certain parameters within the model were not locked on to the PMA database. GoldSim allows you to “lock onto” the file that is being referenced by a file element. When you lock onto a file (by checking the Lock onto this file option in the File element dialog), the following additional information regarding the referenced file is saved with the element: File and path name; Date the file was created; Date the file was last modified; File size; and CRC signature. Once you have locked onto a file, this information is displayed in a tool-tip when you hold your cursor over the filename in the dialog. The PMA simulations used the correct files because they were downloaded from the controlled PMA database when the model was run, and therefore this issue does not affect the dose calculations.</td>
</tr>
<tr>
<td>11</td>
<td>The pH regression equation contains incorrect coefficients. The coefficients in the regression for pH_eq need to be corrected. The value of 7.2625 should be rounded to 7.3. The value of 0.00185 has an extra zero and should also be rounded to 0.02. pH_eq is the pH where the acid and the alkaline dissolution rates cross over, and this pH weakly depends on temperature. For the most part of repository time period, the resulting difference in pH_eq due to the error is less than one unit, which is within the uncertainty range of predicted in-package pH values. Therefore, the impact on annual dose is expected to be negligible.</td>
</tr>
</tbody>
</table>
Table C9-1[a]. Impact Assessment Summary Table (Continued)

<table>
<thead>
<tr>
<th>ISSUE DESCRIPTION</th>
<th>IMPACT ASSESSMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 There are incorrect values in some of the tables used in the in-package chemistry calculations.</td>
<td>Some of the inputs in the PMA database for the lookup tables named: IPC_{XXX}_{pH}<em>Rsw</em>{YY}_Z_LUT (where XXX = CSNF, DHLW, or MCO; YY = 15, 2, 3, or 4; and Z = A-I) has some rows with erroneous data. The DTN that supplied the tables had some independent variables that were duplicated in multiple rows. GoldSim could not read tables with these duplicate independent variables. The DTN supplier indicated that it was acceptable to average these rows together. The error occurred because the analyst who averaged these rows failed to expand out each cell to display the maximum number of significant figures. Therefore some rows were rounded together that did not need to be. No impacts to the dose results are expected. More information is provided in PEF 500. The PEF has a Roadmap to the TSPA-produced DTN that holds the modified lookup tables. This DTN now has two file sets: Uncorrected and Corrected. To correct this error, replace the PMA database entries with the tables in the Corrected folder.</td>
</tr>
<tr>
<td>13 The parameter specifying the value of Np Carbonate Eps is incorrect.</td>
<td>The input in the PMA database for parameter “Np_Carbonate_PMA_Eps” is not correct. It should be a triangular distribution with a=−0.5 and b=0 and c=0.5 rather than a truncated normal distribution. The truncated normal distribution is equally well justified. No impacts to the dose results are expected.</td>
</tr>
<tr>
<td>14 In determining whether the drift chemical environment is benign or aggressive for drip shield general corrosion, 5 mM dissolved fluoride concentration is used instead of 0.5 mM as suggested in C6.3.1.</td>
<td>The value of 5 mM is justifiable because this value is close to the middle point of the fluoride concentration interval within which the corrosion rate starts to increase at the lower bound (0.5 mM) and then levels off at the upper bound (5 mM). Furthermore, this error only affects one out four initial seepage waters used in the model and this effect will diminish as the seepage water composition returns to the ambient conditions after the thermal event. Therefore, the impact of this error is negligible.</td>
</tr>
</tbody>
</table>
### Table C9-1[a]. Impact Assessment Summary Table (Continued)

<table>
<thead>
<tr>
<th>ISSUE DESCRIPTION</th>
<th>IMPACT ASSESSMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td></td>
</tr>
<tr>
<td>The Water Balance submodel incorrectly calculates:</td>
<td>1) The expression for the degradation rate in the CDSP portion of the model should be divided by the number of packages failed to obtain a per-package degradation rate. Otherwise, the rate is too high which keeps the water saturation low and ionic strength high until the steel is gone. Low water saturation may reduce the diffusive release from the waste form. High ionic strength tends to increase radionuclide solubility because of out-of-bound conditions. The overall effect is anticipated to be small because CSNF WPs usually dominate the dose. The early failed scenarios are not affected because they fail only one WP.</td>
</tr>
<tr>
<td>1) the stainless steel degradation rate for Co-disposed (CDSP) WPs.</td>
<td></td>
</tr>
<tr>
<td>2) the average stainless steel degradation rate</td>
<td>2) The stainless steel degradation rate is based on the difference between the volume of corrosion products times the number of failed packages at the current timestep and the previous timestep. However, the corrosion products volume is already an average so this technique is unnecessary. This results in small overestimation of the stainless steel degradation rate when the number of failed WPs increases with time, such as in the Nominal Modeling Case run for the 1,000,000 year duration. The overall effect on dose is anticipated to be small because the water saturation inside the WP would not be greatly affected by this overestimation.</td>
</tr>
<tr>
<td>3) the stainless steel degradation rate by treating all corrosion products as degraded stainless steel</td>
<td>3) The stainless steel degradation rate uses a conversion factor for calculating the volume of corrosion products per kilogram of stainless steel. However, some of the corrosion products in the CDSP WPs are formed from the degradation of carbon steel, which should use a different conversion factor. The effect is anticipated to be small because the conversion factors would be approximately the same.</td>
</tr>
</tbody>
</table>
APPENDIX D[a]
PARAMETER LISTING
DI[a] INTRODUCTION

The Total System Performance Assessment (TSPA) Input Database was updated and includes the parameters used in both TSPA-LA Model v5.000 (documented in the parent document) and TSPA-LA Model v5.005 (documented in this addendum). The details of this database are described in Section 4.7 of the parent document and Section 4[a] of this addendum. Parameter Entry Form series 200 numbers, listed in Tables 4-1[a] and 4-2[a], contain the additional TSPA-LA Model v5.005 parameters. Additionally, Appendix K of the parent report contains two tables that describe the significant uncertain parameters (Tables K.3-1 and K.3-2).
Appendix H[a] includes minor editorial changes from the text included in the parent document when referencing the proposed rule. The supplemental information presented in this addendum should be used to clarify these issues.

H1.1[a] EVALUATION AGAINST 10 CFR 63.113(a); 10 CFR 63.115(a); AND 10 CFR 63.115(b)

No change.

H1.2[a] EVALUATION AGAINST 10 CFR 63.113(b)

No change.

H1.3[a] EVALUATION AGAINST 10 CFR 63.113(c)

Acceptance Criterion 1 and 2 below have been revised slightly from the parent document with some minor updates to the references. The bulk of the information presented is the same as in the parent document.

Acceptance Criterion 1–An Adequate Demonstration is Provided that the Expected Concentration of Combined $^{226}$Ra and $^{228}$Ra, Expected Concentration of Specified Alpha–Emitting Radionuclides, and Expected Whole Body or Organ–Specific Doses from any Photon– or Beta–Emitting Radionuclides at Any Year During the Compliance Period Do Not Exceed the Separate Standards for Protection of Groundwater—Section 8.1.2 presents the results of analyses addressing the separate standards for protection of groundwater in 10 CFR 63.331 [DIRS 180319], Table 1. In particular, Section 8.1.2 shows the estimate of groundwater radioactivity for the representative volume of groundwater that includes combined $^{226}$Ra and $^{228}$Ra, gross alpha activity (including due to $^{226}$Ra, but excluding that due to radon and uranium), and combined beta- and photon-emitting radionuclides. Sections 6.3 and 8.1.2 discuss the methods, assumptions, models, and data used in calculating these estimates. Sections 6.3 and 8.1.2 show that these estimates are consistent with the repository performance assessment calculations for likely processes and events that may occur after disposal, and that the calculations are supported by an adequate technical basis. Therefore, the material in Sections 6.3 and 8.1.2 provides information useful in evaluating Acceptance Criterion 1.

Acceptance Criterion 2–The Methods and Assumptions Used to Determine the Position of the Representative Volume of Groundwater are Credible and Consistent, and the Representative Volume of Groundwater Includes the Highest Concentration Level in the Plume of Contamination in the Accessible Environment—Section 6.3.10 discusses the methods and assumptions for determination of groundwater concentrations in the representative volume that is located along the radionuclide migration path from the repository at Yucca Mountain to the accessible environment. Section 8.1.2 provides results and a detailed evaluation of the concentrations in the context of the groundwater concentration standards (10 CFR 63.331 [DIRS 180319], Table 1). In the TSPA-LA Model, a conservative approach is used in which
radionuclide concentrations are estimated by assuming the entire annual release from the repository system is discharged into the representative volume, located 18 km from the repository (66 FR 55732 [DIRS 156671], III Public Comments and Responses, 3.5, p. 55750). Therefore, the estimated radionuclide concentrations provide an upper bound to the groundwater concentrations needed to assess the groundwater protection requirements. This approach eliminates the need to specify the dimensions of the representative volume or the water usage by the reasonably maximally exposed individual (RMEI) (Section 1.1.1) (10 CFR 63.332(a)(3) [DIRS 180319]). The information provided in Sections 6.3.10 and 8.1.2 therefore, supports evaluation of Acceptance Criterion 2 by the U.S. Nuclear Regulatory Commission (NRC).

Acceptance Criterion 3–The Methods and Assumptions Used to Calculate the Physical Dimensions of the Representative Volume of Groundwater are Credible and Consistent—No changes.

H1.4[a] EVALUATION AGAINST 10 CFR 63.113(d)

Acceptance Criterion 1–Evaluation of the Time of an Intrusion Event—No change.

Acceptance Criterion 2–Evaluation of an Intrusion Event Demonstrates That the Annual Dose to the Reasonably Maximally Exposed Individual in Any Year During the Compliance Period Is Acceptable—Sections 6.7 and 8.1.3 discuss how the TSPA-LA Model addresses the Human Intrusion Scenario, the implementation, and how the resultant RMEI dose complies with the requirement of this acceptance criterion. Section 6.7.3 specifically discusses implementation of the TSPA-LA Model for human intrusion separately from the overall TSPA, and is consistent with the requirements for performance assessments, as specified in NRC Proposed rule 10 CFR 63.114 [DIRS 178394]. Section 6.7 analyzes a postulated human intrusion event with characteristics as defined in 10 CFR 63.322 [DIRS 180319], and excludes the consideration of unlikely natural features, events, or processes (10 CFR 63.342(b) [DIRS 178394]) (Section 6.7.2.2). Sections 6.7.3 and 6.7.4 show that many of the nominal abstractions, process models, and parameters values are used in the analysis of the TSPA-LA Human Intrusion Scenario, and therefore, many of the implementation provisions in Section 6.3 apply to the Human Intrusion Modeling Case. In addition, the numerical values in the Individual Protection Standard in NRC Proposed Rule 10 CFR 63.311(a) [DIRS 178394] are identical to the numerical values of the Individual Protection Standard for Human Intrusion in NRC Proposed Rule 10 CFR 63.321(b) [DIRS 178394]. Section 7.3 provides information regarding the fact that a sufficient number of realizations have been run using the TSPA-LA Model, to ensure that the results of the calculations are statistically stable. Section 8.1.3 discusses the overall system performance analyses and presents the resulting annual dose curves for the Human Intrusion Scenario. The information provided in Sections 6.7 and 8.1 supports confirmation that the repository system meets performance objectives specified in 10 CFR 63.321 [DIRS 178394] for a human intrusion into the repository.

Acceptance Criterion 3—The Total System Performance Assessment Code Provides a Credible Representation of the Intrusion Event—No change.
<table>
<thead>
<tr>
<th>Applicable Sections of 10 CFR Part 63</th>
<th>Associated Section of NUREG-1804 Acceptance Criterion</th>
<th>NUREG-1804 Acceptance Criterion</th>
<th>Section of Report Addressing NUREG-1804 Acceptance Subcriterion</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 CFR 63.113(b) [DIRS 180319] and 10 CFR 63.311 [DIRS 178394]</td>
<td>2.2.1.4.1.3 Demonstration of Compliance with Postclosure Individual Protection Standard</td>
<td>1. Scenario Classes</td>
<td>1. Scenario class screening 6.1.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2. Combining mean annual dose from scenario classes 6.1.2 and 8.1.1.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Mean Annual Doses</td>
<td>1. Number of realizations 7.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2. Uncertainty in mean annual dose 6.1.3 and 8.1.1.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3. Performance of components and subsystems 8.2 – 8.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4. Comparison with individual protection standard (10 CFR 63.311 [DIRS 178394]) 8.1.1.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. Credible TSPA-LA Model</td>
<td>1. Consistency of assumptions 5, 6.3 to 6.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2. Model verification 7.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3. Uncertainty analysis 6.1.3 and 7.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4. Parameter sampling 6.1.3</td>
</tr>
<tr>
<td>10 CFR 63.113(c) [DIRS 180319], 10 CFR 63.331 [DIRS 180319], Table 1, and 10 CFR 63.332 [DIRS 180319]</td>
<td>2.2.1.4.3.3 Demonstration of Compliance with Groundwater Protection Standards</td>
<td>1. Groundwater Protection Standards</td>
<td>1. Compliance with concentration and dose standards 8.1.2.1 to 8.1.2.2, and 8.1.2.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2. Methods and assumptions 8.1.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3. Comparison with groundwater protection standards (10 CFR 63.331 [DIRS 180319], Table 1) 8.1.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Position of Representative Volume</td>
<td>1. Along radionuclide migration path 6.3.10</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2. Method of locating position 6.3.10</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3. Highest concentration 6.3.10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. Dimensions of Representative Volume</td>
<td>1. Specifications on representative volume 8.1.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2. Method to determine dimensions 6.3.10 and 8.1.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3. Consistency with water usage 8.1.2 and 6.3.11</td>
</tr>
</tbody>
</table>
### Table H-1[a]. Applicable Regulatory Requirements of 10 CFR Part 63 and NUREG-1804 Acceptance Criteria Addressed in this Document (Continued)

<table>
<thead>
<tr>
<th>Applicable Sections of 10 CFR Part 63</th>
<th>Associated Section of NUREG-1804 Acceptance Criterion</th>
<th>NUREG-1804 Acceptance Criterion</th>
<th>Section of Report Addressing NUREG-1804 Acceptance Subcriterion</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 CFR 63.113(d) [DIRS 180319], 10 CFR 63.321 [DIRS 178394], and 10 CFR 63.322 [DIRS 180319]</td>
<td>2.2.1.4.2 Demonstration of Compliance with the Human Intrusion Standard</td>
<td>1. Evaluation of the Time of a Human Intrusion Event</td>
<td>6.7.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Evaluation of an Intrusion Event Demonstrates That the Annual Dose to the RMEI in Any Year During the Compliance Period Is Acceptable</td>
<td>6.7.3 and 6.7.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1. The TSPA for the Human Intrusion Scenario is performed separately from the overall TSPA, and meets the requirements for performance assessments, specified in 10 CFR 63.114 [DIRS 178394].</td>
<td>6.7.2.2, 6.7.3, and 6.7.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. The TSPA for the Human Intrusion Scenario is identical to the TSPA for individual protection, except that it assumes the occurrence of a postulated human intrusion event with characteristics, as defined in 10 CFR 63.322 [DIRS 180319] and excludes the consideration of unlikely natural features, events, or processes in 10 CFR 63.342(b) [DIRS 178394].</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. A sufficient number of realizations have been run using the TSPA code, to ensure that the results of the calculations are statistically stable.</td>
<td>8.1.1.2 and 7.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4. The estimated repository performance is reasonable and consistent with the analysis of overall repository performance, and with the characteristics of the postulated Human Intrusion Scenario.</td>
<td>8.1.3.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5. The annual dose curve for limited human intrusion confirms that the repository system meets performance objectives, specified in 10 CFR 63.321 [DIRS 178394], for limited human intrusion events.</td>
<td>8.1.3.2</td>
</tr>
<tr>
<td>Applicable Sections of 10 CFR Part 63</td>
<td>Associated Section of NUREG-1804 Acceptance Criterion</td>
<td>NUREG-1804 Acceptance Criterion</td>
<td>Section of Report Addressing NUREG-1804 Acceptance Subcriterion</td>
</tr>
<tr>
<td>-------------------------------------</td>
<td>-----------------------------------------------------</td>
<td>---------------------------------</td>
<td>---------------------------------------------------------------</td>
</tr>
<tr>
<td>3. The TSPA Code Provides a Credible Representation of a Human Intrusion Event.</td>
<td>1. Assumptions made on the method of transport from a breached waste package within the TSPA for evaluating the postulated intrusion event are consistent among different modules of the code. The use of assumptions and parameter values that differ among modules of the code is adequately documented.</td>
<td>5, 6.7.1 to 6.7.5, and 7.7</td>
<td></td>
</tr>
<tr>
<td>2. The TSPA code for evaluating human intrusion is properly verified, such that there is confidence that the code is modeling the physical processes in the repository system in a manner that is consistent with the characteristics of the postulated intrusion event. The transfer of data between modules of the code is conducted properly.</td>
<td></td>
<td>7.2</td>
<td></td>
</tr>
<tr>
<td>3. The estimate of uncertainty in the performance assessment results is consistent with the uncertainties considered in the characteristics of the postulated intrusion event, and with model and parameter uncertainty.</td>
<td>8.1.3, 6.7.3, 6.1.3, and 7.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. The sampling method used in the TSPA ensures that sampled parameters of the postulated intrusion event have been sampled across their ranges of uncertainty.</td>
<td>6.1.3, 6.7, and 7.4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Sources: 10 CFR Part 63 [DIRS 178394 and DIRS 180319]; NUREG-1804 (NRC 2003 [DIRS 163274]).
APPENDIX I[a]
FEATURES, EVENTS, AND PROCESSES MAPPED TO TSPA-LA MODEL
II[a] INTRODUCTION

Appendix I[a] contains a revision to selected descriptions listed in Table I-2 of the parent document. One new description for the EBS Thermal Hydrologic Environment Submodel is included in Table I-2[a]. Only the table entries that have been revised are included in the updated Table I-2[a] included in this addendum. The corrected table entries should be substituted into the original table presented in Appendix I of the parent document.
<table>
<thead>
<tr>
<th>Submodel Implemented in the TSPA-LA Model and Section Number</th>
<th>Path in GoldSim Model File</th>
<th>FEPs Included in the Submodel</th>
<th>TSPA Inclusion Explanation</th>
<th>Performance Assessment Standard</th>
<th>TSPA-LA Model Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>EBS TH Environment Submodel</strong> 6.3.2</td>
<td>Epistemic: \Input_Params_Epistemic\Epistemic_Params_EBS_Environment\Uncertain_Paramers_TH EBS: \Global_Inputs_and_Calcs\Global_EBS_Environment\ThermoHydrology</td>
<td>2.1.06.06.0A Effects of drip shield on flow</td>
<td>The effects of a drip shield on flow is included in the Multiscale Thermohydrologic Model (MSTHM) by predicting the temperature of the in-drift environment both inside and outside the intact drip shield. Water fluxes in the invert are influenced by temperature and capillary pressure processes. The thermal effects on flow are assessed by multiple MSTHM process model simulations. These simulations are used to develop the MSTHM Abstraction implemented in the TSPA-LA Model.</td>
<td>10 CFR 63.311 10 CFR 63.331 10 CFR 63.321</td>
<td>MA</td>
</tr>
<tr>
<td><strong>WP and DS Degradation Submodel</strong> 6.3.5</td>
<td>Epistemic: \Input_Params_Epistemic\Epistemic_Params_WP_DS_Deg\Aleatory: \Model_Calcs_Aleatory\Aleatory_Calcs_WP_DS_Deg EBS: \Time_Zero\EBS_PS_Loop\Static_Calcs_PS_Loop\Static_Calcs_WP_DS_Deg \Global_Inputs_and_Calcs\Global_WP_DS_Deg\Global_IWPD</td>
<td>2.1.03.05.0A Microbially influenced corrosion of waste packages</td>
<td>Microbially influenced corrosion is modeled in the TSPA-LA Model as an enhancement factor uniformly distributed between 1 and 2 due to uncertainty. The factor is applied to the entire waste package outer barrier general corrosion rate when the relative humidity at the waste package outer corrosion barrier surface is above a threshold value represented by, and sampled from, a uniform distribution ranging from 75 percent to 90 percent.</td>
<td>10 CFR 63.311 10 CFR 63.331</td>
<td>DLL</td>
</tr>
<tr>
<td>Submodel Implemented in the TSPA-LA Model and Section Number</td>
<td>Path in GoldSim Model File</td>
<td>FEPs Included in the Submodel</td>
<td>TSPA Inclusion Explanation</td>
<td>Performance Assessment Standard</td>
<td>TSPA-LA Model Implementation</td>
</tr>
<tr>
<td>-------------------------------------------------------------</td>
<td>-----------------------------</td>
<td>------------------------------</td>
<td>-----------------------------</td>
<td>---------------------------------</td>
<td>------------------------------</td>
</tr>
<tr>
<td>Biosphere Submodel 6.3.11</td>
<td>Epistemic: \Input_Params_Epistemic\Epistemic_Params_Biosphere Other: \TSPA_Model\Biosphere</td>
<td>2.4.01.00.0A Human characteristics (physiology, metabolism)</td>
<td>Metabolic and physiologic considerations consistent with present knowledge of adults, as per 10 CFR 63.312(e) [DIRS 180319], were used in the development of parameter distributions for the external exposure, inhalation, and ingestion submodels. Therefore, this feature, event, or process (FEP) is included in the biosphere component of the TSPA-LA Model through the use of groundwater exposure scenario biosphere dose conversion factors (BDCFs) that are direct inputs to the TSPA-LA for the scenario classes involving radionuclide release to the groundwater, and through the use of the conversion factors for demonstrating compliance with the groundwater protection standards. The annual doses are calculated as the product of radionuclide concentration in groundwater and the BDCFs or conversion factors.</td>
<td>10 CFR 63.311 10 CFR 63.321 10 CFR 63.331</td>
<td>MA</td>
</tr>
</tbody>
</table>

* 10 CFR 63.311 Individual Protection (70 FR 53313 [DIRS 178394]).
10 CFR 63.331 Groundwater Protection (10 CFR 63 [DIRS 180319]).
10 CFR 63.321 Human Intrusion (70 FR 53313 [DIRS 178394]).
APPENDIX J[a]
CONCEPTUAL STRUCTURE OF TSPA-LA
Appendix J of the parent document includes detailed documentation of the TSPA-LA Model conceptual structure. This addendum includes additional supplemental material in Section J3[a] that presents an overview of the underlying concepts used in the TSPA-LA Model, which are described in Appendix J of the parent document. The supplemental material provided in Section J3[a] of this addendum should be reviewed in conjunction with Appendix J included with the parent document.

**J2[a] REQUIREMENTS UNDERLYING CONCEPTUAL STRUCTURE OF TSPA-LA**

No change.

**J3[a] TUTORIAL ON PROBABILITY, UNCERTAINTY AND THE STRUCTURE OF PERFORMANCE ASSESSMENTS**

The conceptual and computational design of the TSPA-LA is based on standard concepts underlying risk assessments for complex systems. An overview of the evolution and development of these concepts is provided in Rechard (1999 [DIRS 145383]).

A natural starting place in a discussion of the antecedents to the TSPA-LA conceptual and computational design is the Reactor Safety Study, which was initiated by the Atomic Energy Commission to study the risk from commercial nuclear power plants and completed by the NRC (1975 [DIRS 107799]). This was a landmark study and constituted the largest systematic risk analysis ever performed at the time of its completion. The primary emphasis of this study was on aleatory uncertainty in the sense of the universe of possible accidents that could occur at a commercial nuclear power plant.

After the completion of the Reactor Safety Study, the NRC commissioned a review of the study that is now commonly referred to as the Lewis Report (Lewis et al. 1978 [DIRS 107800]). This report was highly complimentary of the Reactor Safety Study but had one notable criticism. This criticism was that the Reactor Safety Study had not appropriately assessed and presented the uncertainty in its results. Here, the uncertainty being referred to was of a state of knowledge or epistemic character.

The Reactor Safety Study was highly influential and set the stage for a number of the following risk assessments (e.g., PLG 1983 [DIRS 185063]; PLG 1982 [DIRS 107812]). It was out of this work that the Kaplan/Garrick ordered triple representation for risk emerged (Kaplan and Garrick 1981 [DIRS 100557]). Conceptually, the TSPA-LA can be cast in the context of this representation for risk. However, for computational reasons the TSPA-LA uses a continuous integral-based version of the original ordered triple representation for risk. It was also during this period that Latin hypercube sampling was introduced for use in uncertainty and sensitivity analyses for computationally demanding models (McKay et al. 1979 [DIRS 127905]).

After the publication of the Reactor Safety Study, the NRC initiated the development of a risk assessment methodology at Sandia National Laboratories for the disposal of radioactive waste (Campbell et al. 1978 [DIRS 185064]; Cranwell et al. 1987 [DIRS 185066]). As a result of the
Lewis Committee’s report on the importance of the treatment of (epistemic) uncertainty, the
appropriate treatment of such uncertainty was given high importance in the methodology
development at Sandia (Iman and Conover 1982 [DIRS 165064]; Iman et al. 1980
[DIRS 124198]; and Iman et al. 1978 [DIRS 159559]).

The early work on uncertainty and sensitivity analysis in the preceding project significantly
influenced later analyses for complex systems. In particular, it formed the basis for the treatment
of uncertainty in the NRC’s MELCOR project to develop a new suite of models for reactor
accidents (Iman and Helton 1985 [DIRS 185067]), the NRC’s reassessment of the risk from
commercial nuclear power plants (i.e., the NUREG-1150 analyses) (Breeding et al. 1992
[DIRS 107727]; Breeding et al. 1992 [DIRS 185068]; Brown et al. 1992 [DIRS 185069];
Gregory et al. 1992 [DIRS 185070]; Helton and Breeding 1993 [DIRS 184402]; Payne et al.
1992 [DIRS 185071]; and NRC 1990 [DIRS 107798]), the NRC’s Risk Methods Integration and
Evaluation Program (Payne 1992 [DIRS 107814]), and the U.S. Department of Energy’s
(DOE’s) successful compliance certification application to the U.S. Environmental Protection
Agency (EPA) for the Waste Isolation Pilot Plant (Helton and Marietta 2000 [DIRS 171759];
and DOE 1996 [DIRS 100975]). The basic ideas underlying the treatment of uncertainty and the
performance of associated sensitivity analyses in the preceding analyses are summarized in a
number of review articles (Helton 1993 [DIRS 100452]; Helton 1994 [DIRS 107739]; Helton
1997 [DIRS 107496]; Helton 2003 [DIRS 170558]; Helton and Davis 2003 [DIRS 170518]; and
Helton et al. 2006 [DIRS 183873]).

The conceptual organization of the TSPA-LA is the same as the conceptual organization of the
NRC’s NUREG-1150 analyses and the DOE’s analysis for the Waste Isolation Pilot Plant. Of
course, the details of the analyses are different because different facilities, and hence different
processes and models, are involved. However, the analyses are the same conceptually and have
a structure of the form described in Helton (2003 [DIRS 170558]). Further, all of these analyses
use uncertainty and sensitivity analysis procedures of the form described in Helton and Davis
(2003 [DIRS 170518]) and Helton et al. (2006 [DIRS 183873]). Thus, the TSPA-LA has an
overall conceptual structure that has been successfully used in several preceding and important
analyses. A detailed illustration of the conceptual ideas that underlie the calculation of expected
dose to the reasonably RMEI in the TSPA-LA is presented in Helton and Sallaberry (2007
[DIRS 185072]).

J4[a]  CONCEPTUAL STRUCTURE OF TSPA-LA

No change.

J5[a]  NOMINAL SCENARIO CLASS

No change.

J6[a]  EARLY FAILURE SCENARIO CLASSES

No change.
J7[a] IGNEOUS SCENARIO CLASSES
No change.

J8[a] SEISMIC SCENARIO CLASSES
No change.

J9[a] EXPECTED DOSE FROM ALL SCENARIO CLASSES
No change.

J10[a] JUSTIFICATION FOR ANALYSIS DECOMPOSITION
No change.

J11[a] HUMAN INTRUSION SCENARIO
No change.
INTENTIONALLY LEFT BLANK
APPENDIX K[a]
UNCERTAINTY AND SENSITIVITY ANALYSIS RESULTS
K1[a]  INTRODUCTION

No change.

K2[a]  UNCERTAINTY AND SENSITIVITY ANALYSIS PROCEDURES

No change.

K3[a]  INDEPENDENT AND DEPENDENT VARIABLES

No change.

K4[a]  NOMINAL SCENARIO CLASS

No change.

K4.1[a]  Nominal Scenario Class: Summary

No change.

K4.2[a]  Nominal Scenario Class: Drip Shield (DS) and Waste Package (WP) Failure

No change.

K4.3[a]  Nominal Scenario Class: Engineered Barrier System (EBS) Conditions

No change.

K4.4[a]  Nominal Scenario Class: Release Results Engineered Barrier System (EBS), Unsaturated Zone (UZ) and Saturated Zone (SZ)

No change.

K4.5[a]  Nominal Scenario Class: Dose to Reasonably Maximally Exposed Individual (RMEI)

No substantive changes in the uncertainty and sensitivity analyses for dose to the RMEI (\(DOSTOT\), mrem/yr) over the time interval \([0, 1,000,000\ yr]\) resulting from nominal conditions were observed (i.e., compare the results in Figures K4.5-1 and K4.5-2 with the results in Figures K4.5-1[a] and K4.5-2[a]). Additional comparisons are presented in Figures 7.3.1-18[a] and 7.3.1-19[a] and are discussed in Section 7.3.1.5.1[a].

For reader convenience, the following discussion of the expected dose results in Figures K4.5-1[a] and K4.5-2[a] is provided. This discussion updates Section K4.5 from the parent report.

The uncertainty and sensitivity analyses for total dose to the RMEI (\(DOSTOT\), mrem/yr) are summarized in Figures K4.5-1[a] and K4.5-2[a]. Nonzero values for \(DOSTOT\) begin as early as 20,000 yr as a result of WP failure and then show a general tendency to increase
(Figure K4.5-1a,b[a]). However, some dose curves and especially some of the curves with the largest values for \(DOSTOT\), change from increasing to decreasing at some point in time. This change results from inventory depletion, and hence decreasing or terminating releases, for highly mobile species such as \(^{99}\text{Tc}\) and \(^{129}\text{I}\). All curves remain below 10 mrem/yr.

The PRCCs in Figure K4.5-1c[a] indicate that the uncertainty in \(DOSTOT\) is dominated by \(WDGCA22\) (temperature dependence coefficient associated with the general corrosion rate for Alloy 22, K), with \(DOSTOT\) tending to decrease as \(WDGCA22\) increases. This effect results because the general corrosion rate for Alloy 22 decreases as \(WDGCA22\) increases. Smaller effects are indicated for \(SCCTHR\) (stress corrosion cracking threshold, MPa), \(WDZOLID\) (scale factor used to incorporate uncertainty into the stress intensity factor for closure-lid weld), \(THERMCON\) (host rock thermal conductivity level), \(WDNSCC\) (stress corrosion cracking growth rate exponent), and \(CPUCOLWF\) (concentration of irreversibly attached plutonium on stable glass/waste form colloids, mol/L). The variables \(SCCTHR\), \(WDZOLID\), \(THERMCON\) and \(WDNSCC\) affect \(DOSTOT\) through their effects on WP failure. Specifically, increasing \(SCCTHR\) increases the stress level at which stress corrosion cracking initiates and thus reduces failures at the closure-lid weld; increasing \(WDZOLID\) increases the stress at the closure lid and thus increases failures at the closure-lid weld; increasing \(THERMCON\) tends to lower WP temperatures and thus reduce the rate of corrosion; and increasing \(WDNSCC\) tends to increase the threshold stress intensity factor, which determines the threshold stress at which stress corrosion cracks propagate, and thus reduces failures at the closure-lid weld. The indicated effects of \(CPUCOLWF\) are small and possibly spurious.

The PRCCs in Figure K4.5-1d[a] are for \([200,000; 1,000,000\) years] rather than for \([0; 1,000,000\) years] as is the case for the PRCCs in Figure K4.5-1c[a]. The only substantive difference is the selection of \(INFRCTC\) (initial release fraction for \(^{99}\text{Tc}\) in a CSNF WP) as the last variable in the analysis for \([200,000; 1,000,000\) years]; in contrast \(CPUCOLWF\) is selected as the last variable in the analysis for \([0; 1,000,000\) years]. The PRCCs presented originally in Figure K4.5-1c are for \([0; 1,000,000\) years]; however, the written discussion of the PRCC results in Section K4.5 is for PRCCs obtained for \([200,000; 1,000,000\) years]. As a result, the effects of \(INFRCTC\) are discussed in Section K4.5 although a PRCC for \(INFRCTC\) does not appear in Figure K4.5-1c. The effects for \(INFRCTC\) discussed in Section K4.5 can be seen in Figure K4.5-1d[a].

More detailed sensitivity analysis results for \(DOSTOT\) are provided by the regression results in Figure K4.5-2a[a]. Specifically, \(WDGCA22\) is the dominant variable with \(R^2\) values of 0.78, 0.85 and 0.63 at 400,000 yr, 600,000 yr and 800,000 yr, respectively. Actually, the indicated \(R^2\) values tend to under represent the effect of \(WDGCA22\) because of the nonlinear relationship between \(WDGCA22\) and \(DOSTOT\) that can be seen in Figure K4.5-2b,c,d of Appendix K and is more apparent in Figure K4.5-3 of Appendix K. Specifically, large values of \(WDGCA22\) result in small values for \(DOSTOT\) at late times because of limited WP failure and hence limited radionuclide releases, and small values of \(WDGCA22\) also result in small values for \(DOSTOT\) at late times because of extensive, early WP failure and the resultant reduction in radionuclide inventory by late times.

In addition to \(WDGCA22\), the regressions in Figure K4.5-2a[a] indicate small effects for the following variables that affect WP failure: \(WDZOLID\), \(THERMCON\), \(INFIL\) (infiltration level), \(SCCTHR\), \(WDNSCC\), and \(WDGCUA22\) (pointer variable used to select the distribution of base
corrosion rates of Alloy 22 at 60ºC over the patches on the WPs). The effects of \textit{WDZOLID}, \textit{THERMCON}, \textit{SCCTHR} and \textit{WDNSCC} have already been discussed in conjunction with Figure K4.5-1c[a]. Like \textit{THERMCON}, the negative effect associated with \textit{INFIL} probably results because increased values for \textit{INFIL} result in lower WP temperatures and thus lower rates of corrosion. The variable \textit{WDGCUA22} has a small positive effect on the uncertainty in \textit{DOSTOT}. Specifically, \textit{WDGCUA22} is a pointer variable used to select from three uncertain distributions that derive from both the uncertainty in a base corrosion rate for Alloy 22 at 60ºC and the uncertainty that exists in the prediction of small scale variability in chemical and physical conditions across patches used in the modeling of WP degradation. Increasing \textit{WDGCUA22} results in higher overall corrosion rates and thus higher values for \textit{DOSTOT}. The dominance of \textit{WDGCA22} with respect to the uncertainty associated with \textit{DOSTOT} can be seen in the scatterplot in Figure K4.5-2b[a].

The regressions in Figure K4.5-2a[a] also indicate very small effects of several variables related to physical processes. However, the effects of these variables are minor given the much larger effects of variables related to WP failure and, in particular, the dominant effect of \textit{WDGCA22} on WP failure.

\textbf{K5[a]} \hspace{1cm} \textit{EARLY FAILURE SCENARIO CLASSES}

No change.

\textbf{K5.1[a]} \hspace{1cm} \textit{Early Failure Scenario Classes: Summary}

No change.

\textbf{K5.2[a]} \hspace{1cm} \textit{Early Failure Scenario Classes: Engineered Barrier System (EBS) Conditions}

No change.

\textbf{K5.3[a]} \hspace{1cm} \textit{Early Failure Scenario Classes: Release from Engineered Barrier System (EBS)}

No change.

\textbf{K5.4[a]} \hspace{1cm} \textit{Early Failure Scenario Classes: Release from Unsaturated Zone (UZ)}

No change.

\textbf{K5.5[a]} \hspace{1cm} \textit{Early Failure Scenario Classes: Release from Saturated Zone (SZ)}

No change.

\textbf{K5.6[a]} \hspace{1cm} \textit{Early Failure Scenario Classes: Dose to Reasonably Maximally Exposed Individual (RMEI)}

No change.
K5.7[a] Early Failure Scenario Classes: Expected Dose to Reasonably Maximally Exposed Individual (RMEI)

No change.

K5.7.1[a] Early Failure Scenario Classes: Expected Dose to Reasonably Maximally Exposed Individual (RMEI) from Early Drip Shield (DS) Failure

Expected Dose to RMEI over [0, 20,000 yr]: EXPDOSE. The uncertainty and sensitivity analyses for expected dose to the RMEI (EXPDOSE, mrem/yr) over the time interval [0, 20,000 yr] resulting from early DS failure are summarized in Figures K5.7.1-1[a] and K5.7.1-2[a]. Specifically, Figures K5.7.1-1[a] and K5.7.1-2[a] have the same structure as Figures K5.7.1-1 and K5.7.1-2 but present results calculated with version 5.005 of the TSPA-LA Model rather than with version 5.000 used in the calculation of the results in Figures K5.7.1-1 and K5.7.1-2. A comparison of the results in Figures K5.7.1-1a[a] and K5.7.1-1a obtained with the two versions of the TSPA-LA Model is provided in Figures 7.3.1-20[a] and 7.3.1-22[a]; discussion of the differences in the results is provided in Section 7.3.1.5.2[a]. As examination of Figures 7.3.1-20[a] and 7.3.1-22[a] shows, there is little difference in the values for EXPDOSE obtained with the two versions of the TSPA-LA Model. Consistent with this comparison, there is also little difference in the sensitivity analysis results presented in Figures K5.7.1-1c and K5.7.1-2 for version 5.000 and the corresponding results presented in Figures K5.7.1-1c[a] and K5.7.1-2[a] for version 5.005. As a result, the discussion presented in Section K5.7.1 for EXPDOSE over the time interval [0, 20,000 yr] resulting from early DS failure for results obtained with version 5.000 of the TSPA-LA Model also applies to the results obtained with version 5.005 of the TSPA-LA Model. For this reason, no additional discussion is provided.

For reader convenience, the following discussion of the expected dose results in Figures K5.7.1-1[a] and K5.7.1-2[a] is provided. This discussion updates the corresponding material in Section K5.7.1 from the parent report.

The uncertainty and sensitivity analyses for expected dose to the RMEI (EXPDOSE, mrem/yr) over the time interval [0, 20,000 years] resulting from early DS failure are summarized in Figures K5.7.1-1[a] and K5.7.1-2[a]. There are sharp peaks in EXPDOSE prior to 1000 yr resulting from the release of $^{99}\text{Tc}$. At the time of these peaks, maximum values for EXPDOSE are in the vicinity of 0.01 mrem/yr, although the values for most sample elements are considerably smaller (Figure K5.7.1-1a,b[a]). After the early peaks, EXPDOSE has values in a range from $10^{-7}$ to $10^{-3}$ mrem/yr.

The PRCCs in Figure K5.7.1-1c[a] indicate that the uncertainty in EXPDOSE is dominated by PROBDSEF (probability that a randomly selected DS will experience an early failure), with the value for EXPDOSE increasing as PROBDSEF increases. This effect results because increasing PROBDSEF increases the expected number of DSs that experience early failure and hence increases EXPDOSE.

In addition to PROBDSEF, smaller effects are indicated for SZFIPOVO (flowing interval porosity in the volcanic unit of the SZ), SZGWSPDM (groundwater specific discharge multiplier; as sampled, SZGWSPDM is actually the logarithm of the indicated multiplier), SEEPUNC
(pointer variable used to determine local seepage rates), \textit{INFIL} (infiltration level), and \textit{THERMCON} (host rock thermal conductivity level) (Figure K5.7.1-1c[a]). A negative effect is indicated for \textit{SZFIPOVO} at early times (i.e., prior to 3000 yr), with this effect then going to zero. This effect results because increasing \textit{SZFIPOVO} increases the time required for the initial releases of mobile species such as $^{99}$Tc to reach the location of the RMEI. The positive effect associated with \textit{SZGWSPDM} results from increasing the flow velocity in the SZ, which in turn moves radioactive species more rapidly to the location of the RMEI. This effect is especially pronounced at early times (i.e., prior to 2000 yr) because increasing \textit{SZGWSPDM} decreases the time of first arrival of radioactive species at the location of the RMEI. Both \textit{INFIL} and \textit{THERMCON} have small positive effects on \textit{EXPDOSE} at early times (i.e., prior to 3000 yr). These effects are possibly related to the influence of these variables on repository temperature and hence the time at which release from the EBS can begin. Specifically, increasing \textit{INFIL} and \textit{THERMCON} tends to reduce EBS temperatures and thus reduce the time at which releases from the EBS can begin. After 3000 yr, \textit{THERMCON} has no effect on \textit{EXPDOSE}; however, \textit{INFIL} continues to have a small effect, probably resulting from increased water flow through the EBS and UZ that results as \textit{INFIL} increases in value.

More detailed sensitivity analyses for \textit{EXPDOSE} are provided by the regression analyses in Figure K5.7.1-2a[a]. The dominant effect of \textit{PROBDSEF} on the uncertainty in \textit{EXPDOSE} is indicated by $R^2$ values of 0.70, 0.71 and 0.63 for the regressions containing only \textit{PROBDSEF} at 3000, 5000 and 10,000 yr. After \textit{PROBDSEF}, the most important variable is \textit{SEEPUNC}. However the incremental effect associated with \textit{SEEPUNC} is small as the $R^2$ values for the regression models containing both \textit{PROBDSEF} and \textit{SEEPUNC} are 0.77 and 0.78 at 3000 and 5000 yr, respectively.

After \textit{PROBDSEF} and \textit{SEEPUNC}, smaller effects are indicated for a number of variables (Figure K5.7.1-2a[a]). For example, the following additional variables are indicated as affecting \textit{EXPDOSE} at 10,000 yr: \textit{INFIL}, \textit{SEEPPRM} (mean fracture permeability in lithophysal rock units, m$^2$; as sampled, \textit{SEEPPRM} is actually the logarithm of the indicated permeability), \textit{ALPHAL} (capillary strength parameter in lithophysal rock units), \textit{SZCOLRAL} (colloid retardation factor in alluvial unit of SZ, dimensionless; as sampled, \textit{SZCOLRAL} is actually the logarithm of the indicated retardation factor), \textit{MICPU239} (dose conversion factor for $^{239}$Pu for modern interglacial climate, (rem/yr)/(pCi/L)), \textit{CPUCOLWF} (concentration of irreversibly attached plutonium on stable glass/waste form colloids, mol/L), \textit{SEEPRRMN} (mean fracture permeability in nonlithophysal rock units, m$^2$; as sampled, \textit{SEEPRRMN} is actually the logarithm of the indicated permeability), \textit{RHMU0} (scale factor used to represent uncertainty in chloride concentration in drift waters for relative humidities in the range [0, 0.2]; as sampled, \textit{RHMU0} is actually the logarithm of the indicated scale factor), \textit{SMECSA} (specific surfaces area for smectite colloids, m$^2$/g), \textit{SZGWSPDM} (groundwater specific discharge multiplier; as sampled, \textit{SZGWSPDM} is actually the logarithm of the indicated multiplier), \textit{UZFAG4} (fracture aperture for Group 4 rock units in UZ), and \textit{EPILOWPU} (scale factor used to incorporate uncertainty into plutonium solubility under low ionic strength conditions; as sampled, \textit{EPILOWPU} is actually the logarithm of the indicated scale factor). Specifically, the positive effects associated with \textit{INFIL} and \textit{SEEPUNC} result from increasing water flux through the EBS; the negative effects associated with \textit{SEEPPRM}, \textit{SEEPRRMN} and \textit{ALPHAL} result from increasing water diversion around the EBS; the negative effect associated with \textit{SZCOLRAL} results from increasing colloid
retardation in the SZ; the positive effect associated with MICPU239 results from increasing the received dose for a given exposure to $^{239}$Pu (and possibly other radionuclides due to positive correlations that exist between uncertain dose factors); the positive effect associated with CPUCOLWF results from increasing the amount of plutonium attached to colloids; and the remaining variables have very small effects that may be real or may be spurious.

The dominant effect of PROBDSEF is readily apparent in the scatterplot in Figure K5.7.1-2b[a]. Further, the smaller effects of INFIL and SEEPUNC can be seen in the scatterplots in Figure K5.7.1-2b,c[a].

Two of the variables identified in the analysis with PRCCs (i.e., SZFIPOVO, THERMCON) in Figure K5.7.1-1c[a] do not appear in the regressions in Figure K5.7.1-2a[a]. However, the times at which these variables have identifiable effects on EXPDOSE in Figure K5.7.1-1c[a] are not the times at which the regressions in Figure K5.7.1-2a[a] are performed.

**Expected Dose to RMEI over [0, 1,000,000 yr]: EXPDOSE.** The uncertainty and sensitivity analyses for expected dose to the RMEI (EXPDOSE, mrem/yr) over the time interval [0, 1,000,000 yr] resulting from early DS failure are summarized in Figures K5.7.1-3[a] and K5.7.1-4[a]. Specifically, Figures K5.7.1-3[a] and K5.7.1-4[a] have the same structure as Figures K5.7.1-3 and K5.7.1-4 but present results calculated with version 5.005 of the TSPA-LA Model rather than with version 5.000 used in the calculation of the results in Figures K5.7.1-3 and K5.7.1-4. A comparison of the results in Figures K5.7.1-3[a] and K5.7.1-3a obtained with the two versions of the TSPA-LA Model is provided in Figures 7.3.1-21[a] and 7.3.1-23[a]; discussion of the differences in the results is provided in Section 7.3.1.5.2[a]. As examination of Figures 7.3.1-21[a] and 7.3.1-23[a] shows, there is little difference in the values for EXPDOSE obtained with the two versions of the TSPA-LA Model. Consistent with this comparison, there is also little difference in the sensitivity analysis results presented in Figures K5.7.1-3c and K5.7.1-4 for version 5.000 and the corresponding results presented in Figures K5.7.1-3c[a] and K5.7.1-4[a] for version 5.005. As a result, the discussion presented in Section K5.7.1 for EXPDOSE over the time interval [0, 1,000,000 yr] resulting from early DS failure for results obtained with version 5.000 of the TSPA-LA Model also applies to the results obtained with version 5.005 of the TSPA-LA Model. For this reason, no additional discussion is provided.

For reader convenience, the following discussion of the expected dose results in Figures K5.7.1-3[a] and K5.7.1-4[a] is provided. This discussion updates the corresponding material in Section K5.7.1 from the parent report.

The uncertainty and sensitivity analyses for expected dose to the RMEI (EXPDOSE, mrem/yr) over the time interval [0, 1,000,000 years] resulting from early DS failure are summarized in Figures K5.7.1-3[a] and K5.7.1-4[a]. The time dependent results for EXPDOSE tend to decrease until about 200,000 yr and then level off (Figure K5.7.1-3-a,b[a]). This decrease is due to the decay of $^{239}$Pu, which has a half life of 24,100 yr, and is the largest contributor to expected dose before 200,000 yr (Figure 8.2-4[a]). The values for EXPDOSE are bounded above by 0.01 mrem/yr and, after 200,000 yr, by 0.001 mrem/yr.

The sensitivity analyses for the time interval [0, 1,000,000 yr] are similar to those for the time interval [0, 20,000 yr]. Specifically, the sensitivity analysis with PRCCs for [0, 1,000,000 yr] in
Figure K5.7.1-3c[a] identifies the following variables as influencing the uncertainty in \(\text{EXPDOSE}\): \(\text{PROBDSEF}\) (probability that a randomly selected DS will experience an early failure), \(\text{SEEPPRM}\) (mean fracture permeability in lithophysal rock units, m\(^2\); as sampled, \(\text{SEEPPRM}\) is actually the logarithm of the indicated permeability), \(\text{INFIL}\) (infiltration level), \(\text{SZFIPOVO}\) (flowing interval porosity in the volcanic unit of the SZ), \(\text{SZGWSPDM}\) (groundwater specific discharge multiplier; as sampled, \(\text{SZGWSPDM}\) is actually the logarithm of the indicated multiplier), and \(\text{SEEUPUNC}\) (pointer variable used to determine local seepage rates). Similarly, the sensitivity analysis with PRCCs for \([0, 20,000 \text{ yr}]\) in Figure K5.7.1-1c[a] identifies the following variables as influencing the uncertainty in \(\text{EXPDOSE}\): \(\text{PROBDSEF}\), \(\text{SZFIPOVO}\), \(\text{SZGWSPDM}\), \(\text{SEEUPUNC}\), \(\text{INFIL}\), and \(\text{THERMCON}\) (host rock thermal conductivity level). For both time periods, \(\text{PROBDSEF}\) is the dominant contributor to the uncertainty in \(\text{EXPDOSE}\), with the other variables making much smaller contributions to the uncertainty in \(\text{EXPDOSE}\). The PRCC plots are constrained to contain a maximum of 6 variables. As a result, the slight differences in the variables shown in Figures K5.7.1-1c[a] and K5.7.1-3c[a] result from slight variations in the importance of individual variables over the time intervals under consideration.

More detailed sensitivity analyses for the time interval \([0, 1,000,000 \text{ yr}]\) are provided by the regressions in Figure K5.7.1-4a[a]. Similar to the regressions for \([0, 20,000 \text{ yr}]\) in Figure K5.7.1-2a[a], the dominant variable is \(\text{PROBDSEF}\). Specifically, the dominant effect of \(\text{PROBDSEF}\) on the uncertainty in \(\text{EXPDOSE}\) is indicated by \(R^2\) values of 0.47, 0.55 and 0.52 for the regressions containing only \(\text{PROBDSEF}\) at 50,000, 200,000 and 500,000 yr. These values are lower than the corresponding \(R^2\) values of 0.70, 0.71 and 0.63 obtained in the analyses in Figure K5.7.1-2a[a] at 3000, 5000 and 10,000 yr, which suggests that more variables are having small effects on the uncertainty in \(\text{EXPDOSE}\) at later times than is the case for the first 20,000 yr. This is borne out by the large number of variables indicated as having small effects on \(\text{EXPDOSE}\) in the regression analyses in Figure K5.7.1-4a[a]. After \(\text{PROBDSEF}\), the next most important variable in the three regressions is either \(\text{SZGWSPDM}\) or \(\text{INFIL}\), with \(\text{EXPDOSE}\) tending to increase as \(\text{INFIL}\) increases as a result of increased water flow through the EBS and UZ and also to increase as \(\text{SZGWSPDM}\) increases as a result of increased water flow in the SZ. Together, the first two selected variables result in regressions with \(R^2\) values of 0.55, 0.63 and 0.63 at 50,000, 200,000 and 500,000 yr.

After the first two variables, the three regressions select a subset of \(\text{INFIL}\), \(\text{SEEPPRM}\), \(\text{SZGWSPDM}\), \(\text{EPILOWPU}\) (scale factor used to incorporate uncertainty into plutonium solubility under low ionic strength conditions; as sampled, \(\text{EPILOWPU}\) is actually the logarithm of the indicated scale factor), and \(\text{SEEUPUNC}\) as the next three variables to add to the regression models (Figure K5.7.1-4a[a]). Addition of these three variables brings the \(R^2\) values up to 0.73, 0.77 and 0.75 at 50,000, 200,000 and 500,000 yr. As previously discussed, \(\text{INFIL}\) has positive effect on \(\text{EXPDOSE}\) as a result of increasing water flow through the EBS and UZ; \(\text{SEEPPRM}\) has a negative effect on \(\text{EXPDOSE}\) as a result of increasing water flow around the EBS and thus reducing water flow through the EBS; \(\text{EPILOWPU}\) has a positive effect on \(\text{EXPDOSE}\) as a result of increasing the solubility of plutonium in the EBS; \(\text{SZGWSPDM}\) has a positive effect on \(\text{EXPDOSE}\) as a result of speeding up flow in the SZ; and \(\text{SEEUPUNC}\) has a positive effect on \(\text{EXPDOSE}\) as a result of increasing water flow through the EBS.
After the first five variables, the regressions at 50,000, 200,000 and 500,000 yr add 8, 11 and 11 additional variables, respectively, and produce models with $R^2$ values of 0.82, 0.86 and 0.87 (Figure K5.7.1-4a[a]). Thus, as noted earlier, a large number of variables are having small effects on the uncertainty in $EXPDOSE$ at later times.

The dominant effect of $PROBDSEF$ on the uncertainty in $EXPDOSE$ can also been seen in the scatterplot in Figure K5.7.1-4b[a]. In contrast, the much smaller effects of $INFIL$ and $SEEPPRM$ on the uncertainty in $EXPDOSE$ can been in the scatterplots in Figure K5.7.1-4c,d[a].

K5.7.2[a] Early Failure Scenario Classes: Expected Dose to Reasonably Maximally Exposed Individual (RMEI) from Early Waste Package (WP) Failure

Expected Dose to RMEI over [0, 20,000 yr]: $EXPDOSE$. The uncertainty and sensitivity analyses for expected dose to the RMEI ($EXPDOSE$, mrem/yr) over the time interval [0, 20,000 yr] resulting from early WP failure are summarized in Figures K5.7.2-1[a] and K5.7.2-2[a]. Specifically, Figures K5.7.2-1[a] and K5.7.2-2[a] have the same structure as Figures K5.7.2-1 and K5.7.2-2 but present results calculated with version 5.005 of the TSPA-LA Model rather than with version 5.000 used in the calculation of the results in Figures K5.7.2-1 and K5.7.2-2. A comparison of the results in Figures K5.7.2-1[a] and K5.7.2-1a obtained with the two versions of the TSPA-LA Model is provided in Figures 7.3.1-24[a] and 7.3.1-26[a]; discussion of the differences in the results is provided in Section 7.3.1.5.3[a]. As examination of Figures 7.3.1-24[a] and 7.3.1-26[a] shows, there is little difference in the values for $EXPDOSE$ obtained with the two versions of the TSPA-LA Model. Consistent with this comparison, there is also little difference in the sensitivity analysis results presented in Figures K5.7.2-1c and K5.7.2-2 for version 5.000 and the corresponding results presented in Figures K5.7.2-1c[a] and K5.7.2-2[a] for version 5.005. As a result, the discussion presented in Section K5.7.2 for $EXPDOSE$ over the time interval [0, 20,000 yr] resulting from early WP failure for results obtained with version 5.000 of the TSPA-LA Model also applies to the results obtained with version 5.005 of the TSPA-LA Model. For this reason, no additional discussion is provided.

For reader convenience, the following discussion of the expected dose results in Figures K5.7.2-1[a] and K5.7.2-2[a] is provided. This discussion updates the corresponding material in Section K5.7.2 from the parent report.

The uncertainty and sensitivity analyses for expected dose to the RMEI ($EXPDOSE$, mrem/yr) over the time interval [0, 20,000 yr] resulting from early WP failure are summarized in Figures K5.7.2-1[a] and K5.7.2-2[a]. There are sharp peaks in $EXPDOSE$ between 1000 and 2000 yr resulting from the release of $^{99}$Tc from the failure of CDSP WPs (Figure K5.7.2-1a,b[a]). At the time of these peaks, maximum values for $EXPDOSE$ are in the vicinity of 0.1 mrem/yr, although the values for most sample elements are considerably smaller. After these initial early peaks, $EXPDOSE$ has values in a range from approximately $10^{-5}$ to $10^{-2}$ mrem/yr until a time of about 10,000 yr.

Between approximately 9000 and 14,000 yr, there are sharp jumps in the values for $EXPDOSE$ (Figure K5.7.2-1a,b[a]). These jumps result from the arrival of radionuclide releases at the location of the RMEI that result from the failure of CSNF WPs. The CSNF WPs are hotter than the CDSP WPs, with the result that releases from CSNF WPs are delayed until both the WP
temperature falls below 100ºC and the relative humidity interior to these packages reaches 95 percent, at which time diffusive transport begins. The jumps in EXPDOSE correspond to the arrival of $^{99}$Tc at the location of the RMEI (Figure 8.2-6a[a]). After these jumps, the values for EXPDOSE again decrease as the pulse of $^{99}$Tc passes.

This bimodal behavior of EXPDOSE with different peaks for the two waste types does not occur for early DS failure (compare Figures K5.7.1-1a,b[a] and K5.7.2-1a,b[a]). Early DS failure is assumed to result in WP failure only if the failed DS is experiencing seepage; otherwise, there is no WP failure and hence no radionuclide release. Because all failed WPs are in seepage environments, water flows into every failed WP as soon as WP temperature falls below 100ºC and advective transport occurs immediately, with the result that there is little temporal variability in the start of radionuclide releases from the EBS for different WP types.

The PRCCs in Figure K5.7.2-1c[a] indicate that the uncertainty in EXPDOSE is dominated by PROBWPEF (probability that a randomly selected WP will experience an early failure), with the value for EXPDOSE increasing as PROBWPEF increases. This effect results because increasing PROBWPEF increases the expected number of WPs that experience early failure and hence increases EXPDOSE. The PRCCs for PROBWPEF decrease in value over the period from approximately 9000 to 14,000 yr because of the noise introduced into the analysis as a result of the pulse releases arriving from the failed CSNF WPs.

In addition to PROBWPEF, smaller effects are indicated for SZFIPVO (flowing interval porosity in the volcanic unit of the SZ), THERMCON (host rock thermal conductivity level), INFIL (infiltration level), SZGWSPDM (groundwater specific discharge multiplier; as sampled, SZGWSPDM is actually the logarithm of the indicated multiplier), and DSNFMASS (scale factor used to characterize uncertainty in the amount of DSNF contained in CDSP WPs) (Figure K5.7.2-1c[a]). The effects of SZFIPVO, INFIL, and SZGWSPDM are the same as previously discussed in conjunction with Figure K5.7.1-1c[a]. The effect of THERMCON is similar, although more pronounced. Increasing THERMCON leads to lower drift temperatures and earlier arrival of seepage waters, and thus to earlier beginning of diffusive transport. This effect is evident in the positive correlation between THERMCON and EXPDOSE between 0 yr and 1500 yr. However, between 2500 yr and 9500 yr, the correlation becomes negative. This change in correlation results from the effect of temperature on waste form degradation. Increasing temperature increases the dissolution rate of the HLW in CDSP WPs (BSC 2004 [DIRS 169988], Section 6.5.2.1). Consequently, as THERMCON increases, temperatures decrease and HLW degradation slows, resulting in less radionuclides available for mobilization and transport, and in turn reducing EXPDOSE. This pattern repeats for the CSNF waste, which starts diffusive transport at about 9500 yr. The positive effect associated with DSNFMASS results from increasing the amount of $^{99}$Tc in CDSP WPs and hence the dose from $^{99}$Tc that results from the failure of these WPs.

More detailed sensitivity analyses for EXPDOSE are provided by the regression analyses in Figure K5.7.2-2a[a]. The dominant effect of PROBWPEF on the uncertainty in EXPDOSE is indicated by $R^2$ values of 0.62, 0.77 and 0.47 for the regressions containing only PROBWPEF at 3000, 5000 and 10,000 yr.
As for the PRCCs for PROBWPEF in Figure K5.7.2-1c[a], the $R^2$ value for the regression at 10,000 years decreases in value as a result of the noise introduced into the analysis by the pulse releases arriving from the failed CSNF WPs over the period from approximately 9000 to 14,000 yr. Because of this noise, the final regression model at 10,000 has an $R^2$ value of 0.71; in contrast, the analyses at 3000 and 5000 yr have final $R^2$ values of 0.80 and 0.89. However, a clearer view of what is driving the uncertainty in EXPDOSE at 10,000 yr is provided by the scatterplots in Figure K5.7.2-2b,c,d[a]. Specifically, the uncertainty in EXPDOSE is still clearly dominated by PROBWPEF (Figure K5.7.2-2b[a]), with smaller contributions to this uncertainty from INFIL (Figure K5.7.2-2c[a]) and THERMCON (Figure K5.7.2-2d[a]). The scatterplot for PROBWPEF (Figure K5.7.2-2b[a]) shows an interesting pattern in that it contains two separate populations of points that each increase monotonically with PROBWPEF. The upper population of points consists of realizations in which the CSNF WPs in one or more percolation bins have begun diffusive transport (relative humidity interior to the WP exceeds 95 percent) by 10,000 yr. Because infiltration rates and temperatures vary between percolation bins, the time at which diffusive transport begins also varies, with most CSNF WPs beginning diffusive transport between 9000 yr and 14,000 yr, whereas CDSP WPs begin diffusive transport between 500 yr and 3000 yr. The differences are also apparent in Figure K5.7.2-1a[a] as two jumps in expected dose corresponding to the occurrence of dose from each of the two WP types.

Figure K5.7.2-2c[a] indicates that the expected dose at 10,000 yr decreases as INFIL increases. As INFIL increases, percolation rates tend to increase in most percolation bins, leading to earlier arrival of seepage into a drift. Because increased infiltration also leads to lower temperatures, and at lower drift temperatures, the difference in relative humidity on WPs of different temperatures becomes more pronounced, increasing infiltration results in the counter-intuitive effect that the warmer WPs (CSNF WPs) have lower relative humidity at higher values of infiltration. These lower values of relative humidity are less likely to permit diffusive transport, which in turn yields a negative relationship between INFIL and expected dose at 10,000 years. The relationship between infiltration, temperature and relative humidity is described and documented in Multiscale Thermohydrologic Model (SNL 2007 [DIRS 181383]).

Figure K5.7.2-2c[a] indicates that expected dose at 10,000 yr slightly increases as THERMCON increases. This correlation is valid at 10,000 yr because at this time CSNF WPs are just beginning diffusive transport, so the correlation indicates the positive relationship between THERMCON and EXPDOSE described above. If the correlation were to be performed at later times, after transport has begun, the relationship between THERMCON and EXPDOSE would be reversed, because at these times THERMCON is affecting waste degradation rates, as described above.

In contrast, more informative results are given by the regression analyses at 3000 and 5000 years without the added need to examine scatterplots (Figure K5.7.2-2a[a]). Specifically, both indicated regressions select the following four variables after PROBWPEF: MICTC99 (dose conversion factor for $^{99}$Tc for modern interglacial climate, (rem/yr)/(pCi/L)), MICC14 (dose conversion factor for $^{14}$C for modern interglacial climate, (rem/yr)/(pCi/L)), DSNFMASS, and UZFAG8 (fracture aperture for Group 8 rock units in UZ). Increasing MICTC99 and MICC14 has a positive effect on EXPDOSE that results from increasing the received dose for a given exposure level; increasing DSNFMASS has a positive effect on EXPDOSE that results from increasing the amount of radionuclides in CDSP WPs and hence the dose that results from the
failure of these WPs; and increasing \textit{UZFAG8} has a negative effect on \textit{EXPDOSE} that results from decreasing the proportion of radionuclides moving through fractures in the UZ. Specifically, increasing \textit{UZFAG8} increases the proportion of the interface area between the EBS and the UZ that consists of fractures, which increases the mass of radionuclides that diffuse into fractures in the UZ, where radionuclide movement is relatively rapid, and decreases the mass of radionuclides that diffuse into the surrounding rock matrix, where radionuclide movement is slower. Collectively, the inclusion of \textit{MICTC99}, \textit{MICC14}, \textit{DSNFMASS} and \textit{UZFAG8} increases the $R^2$ values for the two regressions to 0.74 and 0.86. After \textit{MICTC99}, \textit{MICC14}, \textit{DSNFMASS} and \textit{UZFAG8}, the regressions add an additional six and eight variables, respectively, that have small effects and result in final models that have $R^2$ values of 0.80 and 0.89. The regression models at 3000 yr tend to have smaller $R^2$ values than the regression models at 5000 yr because of the noise introduced by the arrival of the $^{99}$Tc releases (i.e., compare the smoothness of the time-dependent releases at 3000 and 5000 yr in Figure K5.7.2-2a,b[a]).

**Expected Dose to RMEI over [0, 1,000,000 yr]: \textit{EXPDOSE}**. The uncertainty and sensitivity analyses for expected dose to the RMEI (\textit{EXPDOSE}, mrem/yr) over the time interval [0, 1,000,000 yr] resulting from early WP failure are summarized in Figures K5.7.2-3[a] and K5.7.2-4[a]. Specifically, Figures K5.7.2-3[a] and K5.7.2-4[a] have the same structure as Figures K5.7.2-3 and K5.7.2-4 but present results calculated with version 5.005 of the TSPA-LA Model rather than with version 5.00 used in the calculation of the results in Figures K5.7.2-3 and K5.7.2-4. A comparison of the results in Figures K5.7.2-3[a] and K5.7.2-3[a] obtained with the two versions of the TSPA-LA Model is provided in Figures 7.3.1-25[a] and 7.3.1-27[a]; discussion of the differences in the results is provided in Section 7.3.1.5.3[a]. As examination of Figures 7.3.1-25[a] and 7.3.1-27[a] shows, there is little difference in the values for \textit{EXPDOSE} obtained with the two versions of the TSPA-LA Model. Consistent with this comparison, there is also little difference in the sensitivity analysis results presented in Figures K5.7.2-3c and K5.7.2-4 for version 5.00 and the corresponding results presented in Figures K5.7.2-3c[a] and K5.7.2-4[a] for version 5.005. As a result, the discussion presented in Section K5.7.2 for \textit{EXPDOSE} over the time interval [0, 1,000,000 yr] resulting from early WP failure for results obtained with version 5.00 of the TSPA-LA Model also applies to the results obtained with version 5.005 of the TSPA-LA Model. For this reason, no additional discussion is provided.

For reader convenience, the following discussion of the expected dose results in Figures K5.7.2-3[a] and K5.7.2-4[a] is provided. This discussion updates the corresponding material in Section K5.7.2 from the parent report.

The uncertainty and sensitivity analyses for expected dose to the RMEI (\textit{EXPDOSE}, mrem/yr) over the time interval [0, 1,000,000 yr] resulting from early WP failure are summarized in Figures K5.7.2-3[a] and K5.7.2-4[a]. Except for a few sample elements, the values for \textit{EXPDOSE} fall between $10^{-6}$ and 0.1 mrem/yr for the 0 to 1,000,000 yr time interval (Figure K5.7.2-3[a]). For most sample elements, the values for \textit{EXPDOSE} monotonically decrease until about 300,000 yr, at which time they show a sharp increase in value as the result of the failure of the DSs from general corrosion (Figure 8.1-4[a]). This failure allows seeping water to directly contact the failed WPs, and as a consequence, produces larger radionuclide releases from the failed WPs.
The single most important variable with respect to the uncertainty in *EXPDOSE* is *PROBWPEF* (probability that a randomly selected WP will experience an early failure), with the value for *EXPDOSE* increasing as *PROBWPEF* increases. This effect results because increasing *PROBWPEF* increases the expected number of WPs that experience early failure and hence increases *EXPDOSE* (Figures K5.7.2-3c[a] and K5.7.2-4a[a]). The positive effect of *PROBWPEF* can be seen in the scatterplot in Figure K5.7.2-4b[a].

Prior to 300,000 yr, *ISCSNS* (pointer variable used to determine ionic strength in CSNF cell under vapor influx conditions) and *SZGWSPDM* (groundwater specific discharge multiplier; as sampled, *SZGWSPDM* is actually the logarithm of the indicated multiplier) also have significant positive effects on the uncertainty in *EXPDOSE* (Figures K5.7.2-3c[a] and K5.7.2-4a[a]). These effects result because increasing *ISCSNS* increases plutonium solubility, and increasing *SZGWSPDM* increases water flow in the SZ. After 300,000 yr, *INFIL* (infiltration level) is indicated as having a positive effect on *EXPDOSE* (Figures K5.7.2-3c[a] and K5.7.2-4a[a]). This effect results because increasing *INFIL* increases water flow in the EBS and UZ. After *PROBWPEF*, *ISCSNS*, *SZGWSPDM* and *INFIL*, the analyses identify a number of additional variables that have small effects on *EXPDOSE*.

K5.7.3[a] Early Failure Scenario Classes: Expected Dose to Reasonably Maximally Exposed Individual (RMEI) from Both Early Drip Shield (DS) Failure and Early Waste Package (WP) Failure

No change.

K5.7.4[a] Early Failure Scenario Classes: Expected Dose to Reasonably Maximally Exposed Individual (RMEI) from Early Drip Shield (DS) Failure, Early Waste Package (WP) Failure, and Nominal Processes

No change.

K6[a] IGNEOUS SCENARIO CLASSES

No change.

K6.1[a] Igneous Scenario Classes: Summary

No change.

K6.2[a] Igneous Intrusive Scenario Classes: Engineered Barrier System (EBS) Conditions over the Time Interval [0, 1,000,000 yr] for an Event at 250 years

No change.

K6.3[a] Igneous Intrusive Scenario Classes: Release from Engineered Barrier System (EBS)

No change.
K6.3.1[a]  Igneous Intrusive Scenario Classes: Release from Engineered Barrier System (EBS) over the Time Interval [0, 20,000 yr] for an Event at 10 years

No change.

K6.3.2[a]  Igneous Intrusive Scenario Classes: Release from Engineered Barrier System (EBS) over the Time Interval [0, 1,000,000 yr] for an Event at 250 years

Results from TSPA-LA Model v5.000 determined that $^{226}$Ra was the dominant contributor to the expected (mean) dose to the RMEI for the Igneous Intrusive Scenario Class (Figure 8.2-8). However, analysis determined that the contribution to expected (mean) dose from $^{226}$Ra was due to an unconstrained distribution describing the uncertainty in longitudinal dispersivity (LDISP in Table K3-1), (see Appendix P, Section P15). For TSPA-LA Model v5.005, the uncertainty distribution for longitudinal dispersivity was constrained so that values sampled from this distribution would be physically meaningful (Section 6.3.10.2[a]). Because of this change, and because of the importance of $^{226}$Ra to expected (mean) dose, additional sensitivity analyses are presented for the transport of radionuclides in the decay chain for $^{226}$Ra, namely $^{234}$U, $^{230}$Th and $^{226}$Ra, for the Igneous Intrusive Scenario Class.

Movement of Dissolved $^{234}$U:  $ESU234$ and $ESU234C$. The uncertainty and sensitivity analyses for the time-dependent release rates ($ESU234$, g/yr) and cumulative releases ($ESU234C$, g) over the time interval [0, 1,000,000 yr] for the movement of dissolved $^{234}$U from the EBS to the UZ resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository are summarized in Figures K6.3.2-5[a] and K6.3.2-6[a].

The dominant contributors to the uncertainty in $ESU234$ and $ESU234C$ are $EP1LOWOU$ (scale factor used to incorporate uncertainty into uranium solubility under low ionic strength conditions after an igneous intrusive event; as sampled, $EP1LOWOU$ is actually the logarithm of the indicated scale factor), $GOESITED$ (density of sorption sites on goethite, sites/nm$^2$), and $INFIL$ (infiltration level) (Figures K6.3.2-5e,f[a] and K6.3.2-6a,b[a]). The variables $EP1LOWOU$ and $INFIL$ have positive effects on $ESU234$ and $ESU234C$ because increasing $EP1LOWOU$ increases uranium solubility and increasing $INFIL$ increases water flow through the EBS. In contrast, increasing $GOESITED$ has a negative effect on $ESU234$ and $ESU234C$ as a result of increasing the sorption of uranium onto corrosion products. All the regression models select $EP1LOWOU$ and $INFIL$ as the first two variables and have $R^2$ values between 0.48 and 0.64 with the inclusion of these two variables (Figure K6.3.2-6a,b[a]).

In addition to $EP1LOWOU$, $GOESITED$ and $INFIL$, generally smaller but significant effects are also indicated for $PHCSS$ (pointer variable used to determine pH in CSNF cell 1 under liquid influx conditions), $CORRATSS$ (corrosion rate for stainless steel, μm/yr), and $HFOSA$ (surface area for hydrous ferrous oxide, m$^2$/g) (Figures K6.3.2-5e,f[a] and K6.3.2-6a,b[a]). The positive effect associated with $PHCSS$ results because increasing $PHCSS$ increases uranium solubility, and the negative effects associated with $CORRATSS$ and $HFOSA$ result because increasing these variables increases uranium sorption on corrosion products. The effect on $ESU234$ associated with $CORRATSS$ varies with time, because while stainless steel is corroding, corrosion products are increasing and the sorption of uranium on the corrosion products reduces the release rate of uranium. However, once corrosion of stainless steel has ceased (roughly at 200,000 yr),
additional corrosion materials are not subsequently produced, so the release rate of uranium is controlled by factors other than the rate at which the corrosion products are generated.

The effects of EPILOWOU, GOESITED, INFIL and PHCSS on ESU234 and ESU234C can be seen in the scatterplots in Figure K6.3.2-6 c,d,e,f,g,h[a]. In particular, the dominant positive effect of EPILOWPU is apparent in Figure K6.3.2-6 c,f[a].

A number of additional variables that have small effects on ESU234 and ESU234C are also identified at the latter stages of the stepwise regressions in Figure K6.3.2-6a,b[a]. The final regression models in Figure K6.3.2-6a,b[a] have $R^2$ values between 0.75 and 0.81. Thus, most of the uncertainty in ESU234 and ESU234C is being accounted for.

**Movement of $^{230}$Th: ESTH230 and ESTH230C.** The uncertainty and sensitivity analyses for the time-dependent release rates (ESTH230, g/yr) and cumulative releases (ESTH230C, g) over the time interval [0, 1,000,000 yr] for the movement of dissolved and reversible attached $^{230}$Th from the EBS to the UZ resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository are summarized in Figures K6.3.2-7[a] and K6.3.2-8[a].

The dominant contributors to the uncertainty in ESTH230 and ESTH230C are INFIL (infiltration level), COLGW (concentration of groundwater colloids when colloids are stable, mg/L), KDTHSMEC (distribution coefficient for reversible sorption of thorium to waste form, i.e., smectite, colloids, mL/g), PHCSS (pointer variable used to determine pH in CSNF cell 1 under liquid influx conditions), EPILOWTH (scale factor used to incorporate uncertainty into thorium solubility at an ionic strength below 1 molal; as sampled, EPILOWTH is actually the logarithm of the indicated scale factor), and UZKDTHTDT (sorption coefficient for thorium in devitrified tuff units of UZ, mL/g; also used as sorption coefficient for thorium in ballast in EBS) (Figures K6.3.2-7e,f[a] and K6.3.2-8a,b[a]). The variables INFIL, COLGW, KDTHSMEC, PHCSS and EPILOWTH have positive effects on ESTH230 and ESTH230C because (1) increasing INFIL increases water flow through the EBS, (2) increasing COLGW and KDTHSMEC increases the amount of thorium sorbed to colloids, and (3) increasing PHCSS and EPILOWTH increases the solubility of thorium. In contrast, increasing UZKDTHTDT has a negative effect on ESTH230 and ESTH230C as a result of increasing the sorption of uranium onto the ballast used in the EBS.

In addition to INFIL, COLGW, KDTHSMEC, PHCSS, EPILOWTH and UZKDTHTDT, the stepwise regression analyses identify several additional variables that have small effects on ESTH230 and ESTH230C (Figure K6.3.2-8a,b[a]). The final regression models contain from 9 to 12 variables and have $R^2$ values between 0.64 and 0.72. To some extent, the regression models are probably being challenged by the difficulty of capturing effects that derive from the decay of $^{234}$U to $^{230}$Th, as well as relationships between concentrations of radionuclides proscribed by the regression model for surface complexation and sorption onto corrosion products (SNL 2007 [DIRS 177407], Section 6.5.2.4). In particular, the positive influence of EPILOWOU (scale factor used to incorporate uncertainty into uranium solubility under low ionic strength conditions after an igneous intrusive event; as sampled, EPILOWOU is actually the logarithm of the indicated scale factor) on ESTH230 and ESTH230C (Figure K6.3.2-8a,b[a]) results from both the decay of $^{234}$U to $^{230}$Th, as well as the negative relationship between the
concentration of dissolved uranium and the concentration of thorium sorbed to corrosion products (SNL 2007 [DIRS 177407], Table 6.5-14).

Overall, the three dominant variables are INFIL, COLGW and KDTHSMEC. The positive effects associated with these variables can be seen in the scatterplots in Figure K6.3.2-8c,d,e,f,g,h[a]).

The PRCCs for COLGW are somewhat larger than the PRCCs for INFIL. In contrast, all the stepwise regression analyses except one select INFIL first and then COLGW. This slight inconsistency possibly results because there is a rank correlation of 0.078 between INFIL and COLGW in the sample in use. In addition, both INFIL and COLGW have rank correlations with other variables that are as high as 0.18 in absolute value. It is possible that some of these correlations could also be affecting the PRCCs in Figure K6.3.2-7e,f[a]; also, the fact that INFIL is a discrete variable with only four levels could be affecting the analysis. However, as is evident from the scatterplots in Figure K6.3.2-8ac,d,f,g[a], both ESTH230 and ESTH230C tend to increase as INFIL and COLGW increase.

Movement of Dissolved $^{226}$Ra: ESRA226 and ESRA226C. The uncertainty and sensitivity analyses for the time-dependent release rates (ESRA226, g/yr) and cumulative releases (ESRA226C, g) over the time interval [0, 1,000,000 yr] for the movement of dissolved $^{226}$Ra from the EBS to the UZ resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository are summarized in Figures K6.3.2-9[a] and K6.3.2-10[a].

The dominant contributors to the uncertainty in ESRA226 and ESRA226C are UZKDCSDT (sorption coefficient for cesium and radium in devitrified tuff units of UZ, mL/g; also used as sorption coefficient for cesium and radium in ballast in EBS), INFIL (infiltration level), and COLGW (concentration of groundwater colloids when colloids are stable, mg/L) (Figures K6.3.2-9e,f[a] and K6.3.2-10a,b[a]). The negative effects associated with UZKDCSDT and COLGW result because (i) increasing UZKDCSDT increases the sorption of $^{226}$Ra to ballast material in the EBS and thus increases the loss of $^{226}$Ra in the EBS as the result of decay and (ii) increasing COLGW increases the removal of $^{230}$Th attached to colloids from the EBS and thus reduces the production of $^{226}$Ra from the decay of $^{230}$Th. The positive effect associated with INFIL results from increasing water flow through the EBS.

Similarly to COLGW, the negative effects on ESRA226 and ESRA226C associated with KDTHSMEC (distribution coefficient for reversible sorption of thorium to waste form, i.e., smectite, colloids, mL/g), PHCSS (pointer variable used to determine pH in CSNF cell 1 under liquid influx conditions), and EPILLOWOU (scale factor used to incorporate uncertainty into uranium solubility under low ionic strength conditions after an igneous intrusive event; as sampled, EPILLOWOU is actually the logarithm of the indicated scale factor) result from increasing the removal of the parent and grandparent of $^{226}$Ra from the EBS. Specifically, increasing KDTHSMEC increases the removal of $^{230}$Th attached to waste form colloids; increasing PHCSS increases the solubility of uranium, thorium and radium; and increasing EPILLOWOU increases the solubility of uranium. In contrast, CSNFMASS (scale factor used to characterize uncertainty in amount of CSNF in CSNF WPs), DSNFMASS (scale factor used to characterize uncertainty in amount of DSNF in DSNF WPs), and GOESITED (density of sorption sites on goethite, sites/nm$^2$) have positive effects on ESRA226 and ESRA226C because
(i) increasing \textit{CSNFMASS} and \textit{DSNFMASS} increases the amount of waste in the repository and (ii) increasing \textit{GOESITED} increases the amount of $^{234}\text{U}$ and $^{230}\text{Th}$ retained in the EBS.

Overall, the three dominant variables are \textit{UZKDCSDT}, \textit{INFIL} and \textit{COLGW}. The effects associated with these variables can be seen in the scatterplots in Figure K6.3.2-10c,d,e,f,g,h[a]. Of the three, \textit{UZKDCSDT} is clearly the most influential variable.

\textbf{K6.4[a] Igneous Intrusive Scenario Classes: Release from Unsaturated Zone (UZ)}

No change.

\textbf{K6.4.1[a] Igneous Intrusive Scenario Classes: Release from Unsaturated Zone (UZ) over the Time Interval [0, 20,000 yr] for an Event at 10 years}

No change.

\textbf{K6.4.2[a] Igneous Intrusive Scenario Classes: Release from Unsaturated Zone (UZ) over the Time Interval [0, 1,000,000 yr] for an Event at 250 years}

\textbf{Movement of Dissolved $^{234}\text{U}$: \textit{UZU234} and \textit{UZU234C}.} The uncertainty and sensitivity analyses for the time-dependent release rates (\textit{UZU234}, g/yr) and cumulative releases (\textit{UZU234C}, g) over the time interval [0, 1,000,000 yr] for the movement of dissolved $^{234}\text{U}$ from the UZ to the SZ resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository are summarized in Figures K6.4.2-1[a] and K6.4.2-2[a]. Further, a comparison of the movement of $^{234}\text{U}$ into and out of the UZ is presented in Figure K6.4.2-3[a]. As shown by the results in Figure K6.4.2-3[a], the movement of $^{234}\text{U}$ into the UZ (i.e., \textit{ESU234C}) is effectively the same as the movement of $^{234}\text{U}$ out of the UZ (i.e., \textit{UZU234C}) for the time scales under consideration. Because of this behavior, the uncertainty and sensitivity analysis results in Figures K6.4.2-1[a] and K6.4.2-2[a] for the release of $^{234}\text{U}$ from the UZ to the SZ are essentially the same as the results in Figures K6.3.2-5[a] and K6.3.2-6[a] for the release of $^{234}\text{U}$ from the EBS to the UZ. As a result, the discussion of the results in Figures K6.3.2-5[a] and K6.3.2-6[a] also applies to the results in Figures K6.4.2-1[a] and K6.4.2-2[a].

\textbf{Movement of Dissolved $^{230}\text{Th}$: \textit{UZTH230} and \textit{UZTH230C}.} The uncertainty and sensitivity analyses for the time-dependent release rates (\textit{UZTH230}, g/yr) and cumulative releases (\textit{UZTH230C}, g) over the time interval [0, 1,000,000 yr] for the movement of dissolved $^{230}\text{Th}$ from the UZ to the SZ resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository are summarized in Figures K6.4.2-4[a] and K6.4.2-5[a]. Further, a comparison of the movement of $^{230}\text{Th}$ into and out of the UZ is presented in Figure K6.4.2-6[a]. As shown by the results in Figure K6.4.2-6[a], the movement of $^{230}\text{Th}$ into the UZ (i.e., \textit{ESU234C}) is related to the movement of $^{230}\text{Th}$ out of the UZ (i.e., \textit{UZU234C}) by a constant fractional shift for the time scales under consideration; specifically, the ratio $^{UZTH230C}$ to $^{ESTH230C}$ is approximately 0.5 for the results in Figure K6.4.2-6[a]. The reduction occurs primarily because of the spatial variability in UZ transport, specifically, $^{230}\text{Th}$ released into the UZ under the northern part of the repository transits through the UZ relatively rapidly, whereas $^{230}\text{Th}$ released into the UZ under the southern part of the repository is very unlikely to ever leave the UZ (SNL 2008 [DIRS 184748], Figure 6.6.2-7[b]). Because the ratio of $^{UZTH230C}$ to
ESTH230C is essentially constant, the uncertainty and sensitivity analysis results in Figures K6.4.2-4[a] and K6.4.2-5[a] for the release of $^{230}$Th from the UZ to the SZ are essentially the same as the results in Figures K6.3.2-7[a] and K6.3.2-8[a] for the release of $^{230}$Th from the EBS to the UZ. This similarity is particularly evident when the stepwise regression analyses in Figures K6.3.2-8a,b[a] and K6.4.2-5[a] are compared. As a result, the discussion of the results in Figures K6.3.2-7[a] and K6.3.2-8[a] also applies to the results in Figures K6.4.2-4[a] and K6.4.2-5[a].

**Movement of Dissolved $^{226}$Ra: UZRA226 and UZRA226C.** The uncertainty and sensitivity analyses for the time-dependent release rates ($UZRA226$, g/yr) and cumulative releases ($UZRA226C$, g) over the time interval [0, 1,000,000 yr] for the movement of dissolved $^{226}$Ra from the UZ to the SZ resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository are summarized in Figures K6.4.2-7[a] and K6.4.2-8[a]. Further, a comparison of the movement of $^{226}$Ra into and out of the UZ is presented in Figure K6.4.2-9[a]. As shown by the results in Figure K6.4.2-9[a], the UZ has noticeable effect on the movement of $^{226}$Ra from the EBS to the SZ; specifically, the releases of $^{226}$Ra out of the UZ are smaller than the releases into the UZ for most sample elements.

The dominant variables affecting the uncertainty in $UZRA226$ and $UZRA226C$ are $UZKDCSDT$ (sorption coefficient for cesium and radium in devitrified tuff units of UZ, mL/g; also used as sorption coefficient for cesium and radium in ballast in EBS), $INFIL$ (infiltration level), $UZFAG8$ (fracture aperture for Group 8 rock unit in UZ, m), and $UZTORRG3$ (tortuosity for Group 3 rock unit in UZ). The negative effects associated with $UZKDCSDT$ and $UZTORRG3$ result because (1) increasing $UZKDCSDT$ increases the retardation of $^{226}$Ra in the EBS and the UZ and (2) increasing $UZTORRG3$ increases the complexity of the transport path in the UZ. The positive effects associated with $INFIL$ and $UZFAG8$ result because (1) increasing $INFIL$ increases water flow in both the EBS and UZ and (2) increasing $UZFAG8$ increases the amount of $^{226}$Ra transported by flow in fractures.

After $UZKDCSDT$, $INFIL$, $UZFAG8$ and $UZTORRG3$, the regression analyses identify several additional variables that have small effects on $UZRA226$ and $UZRA226C$ (Figure K6.4.2-8a,b[a]). Specifically, positive effects are identified for $CSNFMASS$ (scale factor used to characterize uncertainty in amount of CSNF in CSNF WPs), $COLGW$ (concentration of groundwater colloids when colloids are stable, mg/L), $KDHSMEC$ (distribution coefficient for reversible sorption of thorium to waste form, i.e., smectite, colloids, mL/g), and $UZKDTHTD$ (sorption coefficient for thorium in devitrified tuff units of UZ, mL/g; also used as sorption coefficient for thorium in ballast in EBS). These effects result because (1) increasing $CSNFMASS$ increases the amount of waste in the repository, (2) increasing $COLGW$ and $KDHSMEC$ increases the amount of $^{230}$Th that enters the UZ and thus increases the amount of $^{226}$Ra that can be produced by decay in the UZ, and (3) increasing $UZKDTHTD$ increases the retention of $^{230}$Th in the UZ and thus increases the amount of $^{226}$Ra that can be produced by decay in the UZ. A negative effect is indicated for $EPILLOWOU$ (scale factor used to incorporate uncertainty into uranium solubility under low ionic strength conditions after an igneous intrusive event; as sampled, $EPILLOWOU$ is actually the logarithm of the indicated scale factor) and results from the role of $EPILLOWOU$ in mobilizing $^{234}$U in the EBS and thus reducing the
production of $^{226}\text{Ra}$ by the decay of $^{230}\text{Th}$ in the EBS and UZ. Very small effects are indicated for several additional variables.

Scatterplots showing the negative effect of $\text{UZKDCSDT}$ and the positive effects of $\text{INFIL}$ and $\text{UZFAG8}$ are presented in Figure K6.4.2-8c,d,e,f,g,h[a].

K6.5[a] Igneous Intrusive Scenario Classes: Release from Saturated Zone (SZ)

No change.

K6.5.1[a] Igneous Intrusive Scenario Classes: Release from Saturated Zone (SZ) over the Time Interval [0, 20,000 yr] for an Event at 10 years

No change.

K6.5.2[a] Igneous Intrusive Scenario Classes: Release from Saturated Zone (SZ) over the Time Interval [0, 1,000,000 yr] for an Event at 250 years

Movement of Dissolved $^{234}\text{U}$: $\text{SZU234}$ and $\text{SZU234C}$. The uncertainty and sensitivity analyses for the time-dependent release rates ($\text{SZU234}$, g/yr) and cumulative releases ($\text{SZU234C}$, g) over the time interval [0, 1,000,000 yr] for the movement of dissolved $^{234}\text{U}$ across a subsurface plane at the location of the RMEI resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository are summarized in Figures K6.5.2-5[a] and K6.5.2-6[a]. Further, a comparison of the movement of $^{234}\text{U}$ into and out of the SZ is presented in Figure K6.5.2-7[a]. As shown by the results in Figure K6.5.2-7[a], the SZ has a noticeable effect on the movement of $^{234}\text{U}$ in the SZ over the 50,000-yr time period (Figure K6.5.2-7[a]). However, with increasing time, much of the $^{234}\text{U}$ released into the SZ exits the SZ at the location of the RMEI (Figure K6.5.2-7b,c,d[a]). Also, decay of $^{238}\text{U}$ produces $^{234}\text{U}$ within the SZ as can be observed in Figure K6.5.2-7d[a]. Although the half-life of $^{238}\text{U}$ is very long ($4.47 \times 10^9$ yr), the mass of $^{238}\text{U}$ in the inventory is thousands of times greater than the mass of $^{234}\text{U}$ (SNL 2007 [DIRS 180472], Table 7-2[a]), thus decay of $^{238}\text{U}$ over 600,000 yr can produce enough $^{234}\text{U}$ that the additional mass of $^{234}\text{U}$ can be observed in Figure K6.5.2-7d[a].

The dominant variables affecting $\text{SZU234}$ and $\text{SZU234C}$ are $\text{EP1LOWOU}$ (scale factor used to incorporate uncertainty into uranium solubility under low ionic strength conditions after an igneous intrusive event; as sampled, $\text{EP1LOWOU}$ is actually the logarithm of the indicated scale factor), $\text{INFIL}$ (infiltration level), $\text{GOESITED}$ (density of sorption sites on goethite, sites/nm$^2$), $\text{PHCSS}$ (pointer variable used to determine pH in CSNF cell 1 under liquid influx conditions), and $\text{SZGWSPDM}$ (groundwater specific discharge multiplier; as sampled, $\text{SZGWSPDM}$ is actually the logarithm of the indicated multiplier) (Figures K6.5.2-5e,f[a] and K6.5.2-6a,b[a]). The positive effects associated with $\text{EP1LOWOU}$, $\text{INFIL}$ and $\text{PHCSS}$ and the negative effect associated with $\text{GOESITED}$ result from the previously discussed effects of these variables on the release of $^{234}\text{U}$ from the EBS. The positive effect associated with $\text{SZGWSPDM}$ results from increasing water flow in the SZ. Smaller effects are indicated for a number of additional variables.

The dominant effect of $\text{EP1LOWOU}$ and the lesser effects of $\text{INFIL}$ and $\text{GOESITED}$ can be seen in the scatterplots in Figure K6.5.2-6c,d,e,f,g,h[a].
Movement of Dissolved $^{230}$Th: $SZTH230$ and $SZTH230C$. The uncertainty and sensitivity analyses for the time-dependent release rates ($SZTH230$, g/yr) and cumulative releases ($SZTH230C$, g) over the time interval $[0, 1,000,000 \text{ yr}]$ for the movement of dissolved $^{230}$Th across a subsurface plane at the location of the RMEI resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository are summarized in Figures K6.5.2-8[a] and K6.5.2-9[a]. Further, a comparison of the movement of $^{234}$U into and out of the SZ is presented in Figure K6.5.2-10[a]. As shown by the results in Figure K6.5.2-10[a], the SZ has a noticeable effect on the movement of $^{230}$Th from the UZ to the location of the RMEI; specifically, the releases of $^{230}$Th out of the SZ at the location of the RMEI are much smaller than the releases into the SZ for most sample elements.

The dominant variables affecting $SZTH230$ and $SZTH230C$ are $SZCONCOL$ (concentration of colloids in ground water, g/mL; as sampled, $SZCONCOL$ is actually the logarithm of the indicated concentration), $EP1LOWOU$ (scale factor used to incorporate uncertainty into uranium solubility under low ionic strength conditions after an igneous intrusive event; as sampled, $EP1LOWOU$ is actually the logarithm of the indicated scale factor), $SZKDAMCO$ (sorption coefficient for reversible sorption of americium, thorium and protactinium onto ground water colloids, mL/g), $INFIL$ (infiltration level), $SZGWSPDM$ (groundwater specific discharge multiplier; as sampled, $SZGWSPDM$ is actually the logarithm of the indicated multiplier), and $GOESITED$ (density of sorption sites on goethite, sites/nm$^2$) (Figures K6.5.2-8e,f[a] and K6.5.2-9a,b[a]).

The positive effects associated with $SZCONCOL$ and $SZKDAMCO$ result from increasing the amount of $^{230}$Th transported on colloids. The interaction of $SZCONCOL$ and $SZKDAMCO$ in affecting $SZTH230$ and $SZTH230C$ can be seen in the scatterplots in Figure K6.5.2-9c,e,f,h[a]. The positive effects associated with $EP1LOWOU$ and $INFIL$ result from increasing the release of $^{234}$U from the EBS and increasing water flow in the EBS and UZ, respectively. The positive effect associated with $SZGWSPDM$ results from increasing water flow in the SZ. The negative effect associated with $GOESITED$ results from reducing the release of $^{234}$U and $^{230}$Th from the EBS. Smaller effects are indicated for a number of additional variables.

Movement of Dissolved $^{226}$Ra: $SZRA226$ and $SZRA226C$. The uncertainty and sensitivity analyses for the time-dependent release rates ($SZRA226$, g/yr) and cumulative releases ($SZRA226C$, g) over the time interval $[0, 1,000,000 \text{ yr}]$ for the movement of dissolved $^{226}$Ra across a subsurface plane at the location of the RMEI resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository are summarized in Figures K6.5.2-11[a] and K6.5.2-12[a]. Further, a comparison of the movement of $^{226}$Ra into and out of the SZ is presented in Figure K6.5.2-13[a]. As shown by the results in Figure K6.5.2-13[a], the SZ has a large effect on the movement of $^{226}$Ra from the UZ to the location of the RMEI.

Overall, the two most important variables affecting $SZRA226$ and $SZRA226C$ are $EP1LOWOU$ (scale factor used to incorporate uncertainty into uranium solubility under low ionic strength conditions after an igneous intrusive event; as sampled, $EP1LOWOU$ is actually the logarithm of the indicated scale factor) and $SZGWSPDM$ (groundwater specific discharge multiplier; as sampled, $SZGWSPDM$ is actually the logarithm of the indicated multiplier) (Figures K6.5.2-11e,f[a] and K6.5.2-12a,b[a]). The positive effects associated with $EP1LOWOU$ and $SZGWSPDM$ result because increasing $EP1LOWOU$ increases the release of $^{234}$U from the
EBS and increasing \textit{SZGWSPDM} increases water flow in the SZ. The positive effects of \textit{EP1LOWOU} and \textit{SZGWSPDM} can be seen in the scatterplots in Figure K6.5.2-12c,d,f,g[a]. In addition to \textit{EP1LOWOU} and \textit{SZGWSPDM}, a number of additional variables have smaller effects on \textit{SZRA226} and \textit{SZRA226C} (Figures K6.5.2-11e,f[a] and K6.5.2-12a,b[a]).

\textbf{K6.6[a] Igneous Intrusive Scenario Classes: Dose to Reasonably Maximally Exposed Individual (RMEI)}

No change.

\textbf{K6.6.1[a] Igneous Intrusive Scenario Classes: Dose to Reasonably Maximally Exposed Individual (RMEI) over the Time Interval [0, 20,000 yr] for an Event at 10 years}

No change.

\textbf{K6.6.2[a] Igneous Intrusive Scenario Classes: Dose to Reasonably Maximally Exposed Individual (RMEI) over the Time Interval [0, 1,000,000 yr] for an Event at 250 years}

\textbf{Dose to RMEI from Dissolved $^{234}$U: \textit{DOU234}.} The uncertainty and sensitivity analyses for dose to the RMEI (\textit{DOU234}, mrem/yr) over the time interval [0, 1,000,000 yr] for the movement of dissolved $^{234}$U across a subsurface plane at the location of the RMEI resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository are summarized in Figures K6.6.2-5[a] and K6.6.2-6[a].

The uncertainty in \textit{DOU234} is determined primarily by the uncertainty in \textit{SZU234} (Figure K6.6.2-6e[a]). As a result, the analyses in Figures K6.6.2-5[a] and K6.6.2-6[a] for \textit{DOU234} are essentially the same as the analyses in Figures K6.5.2-5[a] and K6.5.2-6[a] for \textit{SZU234}. The only substantive difference is the appearance of \textit{MICU234} (dose conversion factor for $^{234}$U for modern interglacial climate (rem/yr)/(pCi/L)) in the analyses for \textit{DOU234} in Figures K6.6.2-5[a] and K6.6.2-6[a]. The positive effect associated with \textit{MICU234} results from increasing the dose that derives from a unit intake of $^{234}$U.

\textbf{Dose to RMEI from Dissolved $^{230}$Th: \textit{DOTH230}.} The uncertainty and sensitivity analyses for dose to the RMEI (\textit{DOTH230}, mrem/yr) over the time interval [0, 1,000,000 yr] for the movement of dissolved $^{230}$Th across a subsurface plane at the location of the RMEI resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository are summarized in Figures K6.6.2-7[a] and K6.6.2-8[a].

The uncertainty in \textit{DOTH230} is determined primarily by the uncertainty in \textit{SZTH230} (Figure K6.6.2-8e[a]). As a result, the analyses in Figures K6.6.2-7[a] and K6.6.2-8[a] for \textit{DOTH230} are essentially the same as the analyses in Figures K6.5.2-8[a] and K6.5.2-9[a] for \textit{SZTH230}. The only minor difference is the appearance of \textit{MICTH229} (dose conversion factor for $^{229}$Th for modern interglacial climate (rem/yr)/(pCi/L)) in the analyses for \textit{DOTH230} in Figure K6.6.2-8[a]. The positive effect associated with \textit{MICTH229} results from increasing the dose that derives from a unit intake of $^{230}$Th.
**Dose to RMEI from Dissolved $^{226}$Ra: DORA226.** The uncertainty and sensitivity analyses for dose to the RMEI ($DORA226$, mrem/yr) over the time interval [0, 1,000,000 yr] for the movement of dissolved $^{226}$Ra across a subsurface plane at the location of the RMEI resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository are summarized in Figures K6.6.2-9[a] and K6.6.2-10[a].

The uncertainty in $DORA226$ is determined primarily by the uncertainty in $SZRA226$ (Figure K6.6.2-10e[a]). As a result, the analyses in Figures K6.6.2-9[a] and K6.6.2-10[a] for $DORA226$ are essentially the same as the analyses in Figures K6.5.2-11[a] and K6.5.2-12[a] for $SZRA226$. The only minor difference is the appearance of $MICRA226$ (dose conversion factor for $^{226}$Ra for modern interglacial climate (rem/yr)/(pCi/L)) in the analyses for $DORA226$ in Figure K6.6.2-10a[a]. The positive effect associated with $MICRA229$ results from increasing the dose that derives from a unit intake of $^{226}$Ra.

**K6.7[a] Igneous Intrusive Scenario Classes: Expected Dose ($EXPDOSE$) to Reasonably Maximally Exposed Individual (RMEI)**

No change.

**K6.7.1[a] Igneous Intrusive Scenario Classes: Expected Dose ($EXPDOSE$) to Reasonably Maximally Exposed Individual (RMEI) over [0, 20,000 yr]**

No substantive changes in the uncertainty and sensitivity analyses for expected dose to the RMEI ($EXPDOSE$, mrem/yr) over the time interval [0, 20,000 yr] resulting from igneous intrusion were observed (i.e., compare the results in Figures K6.7.1-1 and K6.7.1-2 with the results in Figures K6.7.1-1[a] and K6.7.1-2[a]). Additional comparisons are presented in Figures 7.3.1-28[a] and 7.3.1-30[a]; discussion of the differences in the results is provided in Section 7.3.1.5.4[a].

**K6.7.2[a] Igneous Intrusive Scenario Classes: Expected Dose ($EXPDOSE$) to Reasonably Maximally Exposed Individual (RMEI) over [0, 1,000,000 yr]**

No substantive changes in the uncertainty and sensitivity analyses for expected dose to the RMEI ($EXPDOSE$, mrem/yr) over the time interval [0, 1,000,000 yr] resulting from igneous intrusion were observed (i.e., compare the results in Figures K6.7.2-1 and K6.7.2-2 with the results in Figures K6.7.2-1[a] and K6.7.2-2[a]). Additional comparisons are presented in Figures 7.3.1-29[a] and 7.3.1-31[a]; discussion of the differences in the results is provided in Section 7.3.1.5.4[a].

**K6.8[a] Igneous Eruptive Scenario Classes: Expected Dose ($EXPDOSE$) to Reasonably Maximally Exposed Individual (RMEI)**

No change.

**K6.8.1[a] Igneous Eruptive Scenario Classes: Expected Dose ($EXPDOSE$) to Reasonably Maximally Exposed Individual (RMEI) over [0, 20,000 yr]**

No change.

MDL-WIS-PA-000005 REV 00 AD 01 K-21[a] March 2008
K6.8.2[a]  Igneous Eruptive Scenario Classes: Expected Dose (EXPDOSE) to Reasonably Maximally Exposed Individual (RMEI) over [0, 1,000,000 yr]

No change.

K7[a]  SEISMIC SCENARIO CLASSES

No change.

K7.1[a]  Seismic Scenario Classes: Summary

No change.

K7.2[a]  Seismic Ground Motion Scenario Classes: Engineered Barrier System (EBS) Conditions over the Time Interval [0, 20,000 yr]

No change.

K7.3[a]  Seismic Ground Motion Scenario Classes: Release from Engineered Barrier System (EBS) over the Time Interval [0, 20,000 yr]

No change.

K7.4[a]  Seismic Ground Motion Scenario Classes: Release from Unsaturated Zone (UZ) over the Time Interval [0, 20,000 yr]

No change.

K7.5[a]  Seismic Ground Motion Scenario Classes: Release from Saturated Zone (SZ) over the Time Interval [0, 20,000 yr]

No change.

K7.6[a]  Seismic Ground Motion Scenario Classes: Dose to Reasonably Maximally Exposed Individual (RMEI) over the Time Interval [0, 20,000 yr]

No change.

K7.7[a]  Seismic Ground Motion Scenario Classes: Expected Dose (EXPDOSE) to Reasonably Maximally Exposed Individual (RMEI)

K7.7.1[a]  Seismic Ground Motion Scenario Classes: Expected Dose (EXPDOSE) to Reasonably Maximally Exposed Individual (RMEI) over the Time Interval [0, 20,000 yr]

No substantive changes in the uncertainty and sensitivity analyses for expected dose to the RMEI (EXPDOSE, mrem/yr) over the time interval [0, 20,000 yr] resulting from seismic ground motion were observed (i.e., compare the results in Figures K7.7.1-1 and K7.7.1-2 with the results in Figures K7.7.1-1[a] and K7.7.1-2[a]). Additional comparisons are presented in
Figures 7.3.1-32[a] and 7.3.1-33[a]; discussion of these comparisons is provided in Section 7.3.1.5.6[a].

For reader convenience, the following discussion of the expected dose results in Figures K7.7.1-1[a] and K7.7.1-2[a] is provided. This discussion updates the corresponding material in Section K7.7.1 from the parent report.

The uncertainty and sensitivity analyses for expected dose to the RMEI (EXPDOSE, mrem/yr) over the time interval [0, 20,000 yr] resulting from seismic ground motion events are summarized in Figures K7.7.1-1[a] and K7.7.1-2[a]. After the earliest arrival of released radionuclides at the location of the RMEI, EXPDOSE increases monotonically with time (Figure K7.7-1a,b[a]). At 10,000 yr, the value for EXPDOSE falls between $10^{-4}$ and 1 mrem/yr for most sample elements, with a few sample elements having values for EXPDOSE between 1 and 10 mrem/yr. Due to the use of the quadrature-based methods rather than Monte Carlo methods to evaluate expected dose to the RMEI over the time interval [0, 20,000 yr] (see Equations J8.3-8 and J8.3-13), the expected dose results in Figure 7.7.1-1a,b[a] are relatively smooth.

The PRCCs in Figure K7.7.1-1c[a] indicate that the uncertainty in EXPDOSE is dominated by residual stress threshold SCCTHRP (as sampled, SCCTHRP is a percent of a base value of 351 MPa and is related to the stress corrosion cracking threshold, SCCTHR, by $SCCTHRP = (SCCTHR \times 100)/(351 \text{ MPa})$). The value for EXPDOSE decreases as SCCTHRP increases. This effect occurs because increasing SCCTHRP increases the stress required to initiate stress corrosion cracking and thus decreases the probability that a given seismic ground motion event will cause WP damage.

In addition to SCCTHRP, smaller effects are indicated for SZGWSPDM (groundwater specific discharge multiplier; as sampled, SZGWSPDM is actually the logarithm of the indicated multiplier), SZFIPOVO (flowing interval porosity in the volcanic unit of the SZ), INFIL (infiltration level), DSNFMASS (scale factor used to characterize uncertainty in the radionuclide content of DSNF contained in CDSP WPs), and MICC14 (dose conversion factor for $^{14}$C for modern interglacial climate, (rem/yr)/(pCi/L)) (Figure K7.7.1-1c[a]). The variables SZGWSPDM, DSNFMASS and MICC14 have positive effects on EXPDOSE, with these effects resulting because (1) increasing SZGWSPDM increases water flow in the SZ, (2) increasing DSNFMASS increases the amount of radionuclides in CDSP WPs and hence the dose from the failure of these WPs, and (3) increasing MICC14 increases the received dose from $^{14}$C for a given exposure level. The variables SZFIPOVO and INFIL have effects at early times, but limited effects at later times. The negative effect for SZFIPOVO results from slowing water flow in the SZ and thus delaying the initial arrival of radionuclides at the location of the RMEI. In contrast, the positive effect for INFIL results from accelerating the initial arrival of radionuclides at the location of the RMEI; specifically, increased values for INFIL result (1) in cooler conditions in the EBS, which contributes to earlier radionuclide releases, and (2) in more water flux in the EBS and UZ, which contributes to more rapid radionuclide movement. Owing to the nature of the integration process that defines EXPDOSE, the indicated effects associated with SZFIPOVO and INFIL decrease with increasing time.
More detailed sensitivity analyses for \textit{EXPDOSE} are provided by the regression analyses in Figure K7.7.1-2[a]. The dominant effect of \textit{SCCTHRP} on the uncertainty in \textit{EXPDOSE} is indicated by $R^2$ values of 0.81, 0.86 and 0.88 for the regressions containing only \textit{SCCTHRP} at 3000, 5000 and 10,000 yr. After \textit{SCCTHRP}, the regressions select a large number of variables that have small effects on \textit{EXPDOSE}. For example, the regression at 3000 yr then selects \textit{SZGWSPDM}, \textit{INFIL} and \textit{MICTC99} (dose conversion factor for $^{99}$Tc for modern interglacial climate, (rem/yr)/(pCi/L)) and produces a model with an $R^2$ value of 0.87; the regression at 5,000 yr then selects \textit{MICTC99}, \textit{DSNFMAS} and \textit{MICC14} and produces a model with an $R^2$ value of 0.90; and the regression at 10,000 yr then selects \textit{MICTC99}, \textit{DSNFMAS} and \textit{HLWDRACD} (rate term for dissolution of HLW glass in CDSP WPs under low pH conditions, g/m$^2$/d) and produces a model with an $R^2$ value of 0.91. After the first four variables, the regressions at 3000, 5000 and 10,000 yr select an additional 12, 11 and 12 variables, respectively, and produce final models with $R^2$ values of 0.92, 0.94 and 0.95. Thus, the uncertainty in \textit{EXPDOSE} is dominated by \textit{SCCTHRP}, with small contributions to this uncertainty by many additional variables.

The doses that are integrated to obtain \textit{EXPDOSE} arise primarily from $^{99}$Tc (Figure 8.2-12(a) and Figure J8.3-8). The importance of $^{99}$Tc to \textit{EXPDOSE} is also evident in the regression results at 10,000 yr (Figure K7.7.1-2[a]). Specifically, the three variables selected immediately after \textit{SCCTHRP} (i.e., \textit{MICTC99}, \textit{DSNFMAS} and \textit{HLWDRACD}) are variables that affect the dose received from $^{99}$Tc. Specifically, increasing \textit{MICTC99} increases the dose received from a fixed concentration of $^{99}$Tc in groundwater; increasing \textit{DSNFMAS} increases the mass of $^{99}$Tc present to be released from the CDSP WPs; and increasing \textit{HLWDRACD} increases the rate at which $^{99}$Tc is released from the glass waste form.

The dominant effect of \textit{SCCTHRP} on the uncertainty in \textit{EXPDOSE} can be seen in the scatterplot in Figure K7.7.1-2b[a]. The much smaller effects associated with \textit{MICTC99} and \textit{DSNFMAS} can be seen in the scatterplots in Figure K7.7.1-2c,d[a].

It is important to recognize that the results in Figures K7.7.1-1[a] and K7.7.1-2[a] reflect the sensitivity of \textit{EXPDOSE} to the parameters that are treated as being uncertain in the TSPA-LA Model. Some important parameters and model inputs are not treated as being uncertain, but are instead represented by conservative, fixed values or by assumptions. The sensitivity of \textit{EXPDOSE} to these parameters can be discussed qualitatively but cannot be quantified. For example, the results in Figures K7.7.1-1[a] and K7.7.1-2[a] were generated with a fixed value for the seismic hazard curve, estimated as the mean of a distribution of possible seismic hazard curves. This mean seismic hazard curve underlies the probabilistic weightings of the seismic events that give rise to \textit{EXPDOSE} through an integration process (Section 6.1.2.4.4). Significant uncertainty is associated with the definition of the mean seismic hazard curve (SNL 2007 [DIRS 176828], Section 6.4.1). If the uncertainty associated with the seismic hazard curve was incorporated into the analysis, it is likely that this uncertainty would have a significant effect on the uncertainty associated with \textit{EXPDOSE}. Including this uncertainty in the TSPA-LA Model would likely improve the estimated repository performance, because the mean seismic hazard curve typically lies above the 80th percentile of the distribution of seismic hazard curves. Including the uncertainty in the seismic hazard curve would reduce the frequency of damaging seismic events in most realizations, which would reduce releases from the repository and...
improve repository performance. Thus, the use of the mean seismic hazard curve results in conservative estimates of repository performance.

**K7.7.2[a]** **Seismic Ground Motion Scenario Classes: Expected Dose (\textit{EXPDOSE}) to Reasonably Maximally Exposed Individual (RMEI) over the Time Interval [0, 1,000,000 yr]**

The results obtained with version 5.005 of the TSPA-LA Model in the uncertainty analyses for expected dose to the RMEI (\textit{EXPDOSE}, mrem/yr) over the time interval [0, 1,000,000 yr] resulting from seismic ground motion tend to be somewhat smaller than the results obtained with version 5.000 of the TSPA-LA Model (i.e., compare the results in Figures K7.7.2-1 and K7.7.2-2 with the results in Figures K7.7.2-1[a] and K7.7.2-2[a]). Additional comparisons are presented in Figures 7.3.1-35[a] and 7.3.1-36[a]; discussion of the differences in the results is provided in Section 7.3.1.5.6[a]. However, there is a large amount of variability in the comparisons across sample elements, with (1) version 5.005 producing smaller results for some sample elements, (2) version 5.000 producing smaller results for some sample elements, and (3) both versions producing similar results for some sample elements (Figures K7.3.1-35[a] and 7.3.1-36[a]). The major cause for the difference in the results from both model versions is the change to the models for estimating damage from seismic events, as described in Appendix P, Section P3, with other minor effects from the other errors described in Appendix P. To some extent, this variability is also influenced by the use of only 30 futures in the estimation of \textit{EXPDOSE} for each sample element. The sensitivity analyses tended to agree on the two most important variables but showed considerable disagreement on less important variables. The differences in sensitivity analysis results are due to the differences between the model versions, primarily to the time and extent of seismic damage (Appendix P, Section P3), and secondarily to the processes by which radionuclide transport occurs.

For reader convenience, the following discussion of the expected dose results in Figures K7.7.2-1[a] and K7.7.2-2[a] is provided. This discussion updates the corresponding material in Section K7.7.2 from the parent report.

The uncertainty and sensitivity analyses for expected dose to the RMEI (\textit{EXPDOSE}, mrem/yr) over the time interval [0, 1,000,000 yr] resulting from seismic ground motion are summarized in Figures K7.7.2-1[a] and K7.7.2-2[a].

The time-dependent values for \textit{EXPDOSE} for the 1,000,000-yr period in Figure K7.7.2-1a,b[a] are much choppier than the values for the 20,000 yr time period in Figure K7.7.1-1a,b[a]. This difference results from the numerical procedures used over 20,000-yr and 1,000,000-yr, respectively, to evaluate the integrals that define \textit{EXPDOSE}. Because the effects of the seismic ground motion events are relatively well behaved for the 20,000-yr time period, it is possible to use a quadrature procedure to evaluate \textit{EXPDOSE} for this time period. This results in the relatively smooth time-dependent values for \textit{EXPDOSE} in Figure K7.7.1-1a,b[a]. In contrast, the effects of seismic ground motion events are much more complex for the 1,000,000-yr time period. As a result of this complexity, it is not possible to use a quadrature procedure to evaluate the defining integral for \textit{EXPDOSE} over this longer time period. Instead, it was necessary to use a sampling-based (i.e., Monte Carlo) integration procedure to evaluate the defining integral for \textit{EXPDOSE}. Specifically, thirty 1,000,000-yr futures involving seismic ground motion events.
were randomly sampled for each LHS element and then the 30 time-dependent dose results associated with these futures were vertically averaged at each point in time to produce the estimated time-dependent value for EXPDOSE for each sample element (Appendix J, Figures J8.4-1 and J8.4-2). Because individual seismic ground motion events are discrete occurrences that initiate radionuclide releases that ultimately lead to doses to the RMEI, the time dependent doses associated with individual futures and their vertical averages to produce expected doses for individual LHS elements tend to be choppy. In addition, the progression of nominal processes and the occurrence of resultant DS and WP failures contribute to the complexity of the 1,000,000-yr dose calculations. The individual curves in Figure K7.7.2-1a,b would eventually converge to smooth curves if a sufficiently large number of futures was sampled for each LHS element, or if an appropriate kernel smoother was used on the time-dependent results for each LHS element. However, despite the lack of smoothness in the results presented in Figure 7.7.2-1a,b[a], the distribution of expected annual doses (EXPDOSE) is shown to be statistically stable (Section 7.3.1) by means of a replicated sampling procedure (Section J4.10). In addition, confidence intervals are computed that show that the mean annual dose is estimated with sufficient accuracy (Section 7.3.1). The stability of the results from TSPA-LA Model v5.005 is discussed in Section 7.3.1.5[a].

Most values for EXPDOSE in Figure K7.7.2-1a,b[a] are less than 10 mrem/yr, with a few values between 10 and 100 mrem/yr. The sharp peaks in EXPDOSE in Figure K7.7.2-1a,b[a] are associated with peaks that derive from single seismic ground motion events sampled in a single future. The peaks in EXPDOSE would be reduced if the sampling-based approximations to the integrals defining EXPDOSE were more fully converged.

Although the results in Figure K7.7.2-1a,b[a] are choppy, insights can be gained from a careful examination. In particular, Figure K7.7.2-1b[a] is more informative than Figure K7.7.2-1a[a] because the time-dependent values for EXPDOSE for individual LHS elements are more distinct. Overall, after an initial peak, there is a tendency for EXPDOSE to decrease up to about 200,000 yr, with this decrease resulting from the depletion of soluble radionuclides (i.e. 99Tc and 129I) in WPs with seismic damage (Figure 8.2-12[a]). In this time period, the values of EXPDOSE derive from the occurrence of seismic ground motion events as the failure of WPs from nominal processes does not begin until about 200,000 yr. The dominance of seismic ground motion events is indicated by the importance of the residual stress threshold SCCTHRP (as sampled, SCCTHRP is a percent of a base value of 351 MPa and is related to the stress corrosion cracking threshold, SCCTHR, by SCCTHRP = (SCCTHR × 100)/(351 MPa)); specifically, the PRCCs in Figure K7.7.2-1c[a] indicate that SCCTHRP dominates the uncertainty in EXPDOSE out to approximately 200,000 yr. This result is also indicated by the regression for EXPDOSE at 50,000 yr in Figure K7.7.2-2a [a], where SCCTHRP is the first variable selected in the analysis with an $R^2$ value of 0.71.

Beyond 200,000 years, corrosion processes become important to EXPDOSE as WPs that have not been damaged by seismic events begin to fail by SCC of lid welds (Section 8.2.1[a]). Consistent with this, the PRCCs in Figure K7.7.2-1c[a] indicate that the uncertainty in EXPDOSE becomes dominated by WDGCA22 (temperature dependence coefficient associated with the general corrosion rate for Alloy 22, K). Specifically, WDGCA22 corresponds to a coefficient used to alter the general corrosion rate for Alloy 22 as function of temperature, with the Alloy 22 corrosion rate decreasing as WDGCA22 increases. As indicated in
Figures K4.2-2e,f and K4.5-1c[a], WDGCA22 is the dominant variable with respect to the uncertainty associated with the failure of WPs from nominal processes. After 400,000 yr, the values for EXPDOSE tend to increase and beyond 700,000 years are somewhat smoother than at earlier times (Figure K7.7.2-1a,b[a]). This smoothness results from an increasing dominance of nominal corrosion processes in the values for EXPDOSE.

In addition to SCCTHRP and WDGCA22, the PRCCs in Figure K7.7.2-1c[a] indicate effects for several additional variables. However, the effects are small and the PRCCs are very choppy as a result of the choppiness in the values for EXPDOSE. Smoother results for EXPDOSE would result in smoother values for the PRCCs in Figure K7.7.2-1c[a].

More detailed sensitivity analyses for EXPDOSE are provided by the regression analyses in Figure K7.7.2-2a[a]. Specifically, SCCTHRP is the dominant contributor to the uncertainty in EXPDOSE at 50,000 yr; SCCTHRP is the dominant contributor to the uncertainty in EXPDOSE at 200,000 yr with a contribution from WDGCA22; and WDGCA22 is the dominant contributor to the uncertainty in EXPDOSE at 500,000 yr with a contribution from SCCTHRP. The individual regressions then add several additional variables that have small effects on EXPDOSE. The final regression models 50,000, 200,000 and 500,000 yr have $R^2$ values of 0.77, 0.62 and 0.76, which are not particularly high due in part to the choppiness of the values for EXPDOSE (Figure K7.7.2-1a,b[a]) and in part to the large number of processes that affect EXPDOSE for the 1,000,000 yr seismic ground motion calculation.

For perspective, the scatterplots in Figure K7.7.2-2b,c,d[a] show the effects of WDGCA22, SCCTHRP and WDNSCC (stress corrosion cracking growth rate exponent) at 500,000 yr. The negative effects of WDGCA22 and SCCTHRP can be easily seen in the scatterplots in Figure K7.7.2-2b,c[a]. The negative effect for WDNSCC is more subtle but still discernable in the scatterplot in Figure K7.7.2-2d[a].

As previously indicated in conjunction with Figures K7.7.1-1[a] and K7.7.1-2[a] for the 20,000-year time period, it is important to recognize that the results in Figures K7.7.2-1[a] and K7.7.2-2[a] reflect the sensitivity of EXPDOSE for the 1,000,000-yr time period to those parameters that are treated as being uncertain in the TSPA-LA Model. Some important parameters and model inputs are not treated as being uncertain, but are instead represented by conservative, fixed values or by assumptions. The sensitivity of EXPDOSE to these parameters can be discussed qualitatively but cannot be quantified. In particular, significant uncertainty is associated with the definition of the seismic hazard curve that underlies the occurrence of seismic events and the effects of seismic events. If the uncertainty associated with the seismic hazard curve was incorporated into the analysis, it is likely that this uncertainty would have a significant effect on the uncertainty associated with EXPDOSE.

K7.8[a] Seismic Fault Displacement Scenario Classes: Expected Dose (EXPDOSE) to Reasonably Maximally Exposed Individual (RMEI)

No change.
K7.8.1[a] Seismic Fault Displacement Scenario Classes: Expected Dose (EXPDOSE) to Reasonably Maximally Exposed Individual (RMEI) over the Time Interval [0, 20,000 yr]

No substantive changes in the uncertainty and sensitivity analyses for expected dose to the RMEI (EXPDOSE, mrem/yr) over the time interval [0, 20,000 yr] resulting from fault displacement were observed (i.e., compare the results in Figures K7.8.1-1 and K7.8.1-2 with the results in Figures K7.8.1-1[a] and K7.8.1-2[a]). Additional comparisons are presented in Figures 7.3.1-37[a] and 7.3.1-39[a]; discussion of the differences in the results is provided in Section 7.3.1.5.7[a].

K7.8.2[a] Seismic Fault Displacement Scenario Classes: Expected Dose (EXPDOSE) to Reasonably Maximally Exposed Individual (RMEI) over the Time Interval [0, 1,000,000 yr]

No substantive changes in the uncertainty and sensitivity analyses for expected dose to the RMEI (EXPDOSE, mrem/yr) over the time interval [0, 1,000,000 yr] resulting from fault displacement were observed (i.e., compare the results in Figures K7.8.2-1 and K7.8.2-2 with the results in Figures K7.8.2-1[a] and K7.8.2-2[a]). Additional comparisons are presented in Figures 7.3.1-38[a] and 7.3.1-40[a]; discussion of the differences in the results is provided in Section 7.3.1.5.7[a].

K8[a] ALL SCENARIO CLASSES: EXPECTED DOSE (EXPDOSE) TO REASONABLY MAXIMALLY EXPOSED INDIVIDUAL (RMEI)

No change.

K8.1[a] All Scenario Classes: Expected Dose (EXPDOSE) to Reasonably Maximally Exposed Individual (RMEI) over the Time Interval [0, 20,000 yr]

No substantive changes in the uncertainty and sensitivity analyses for expected dose to the RMEI (EXPDOSE, mrem/yr) over the time interval [0, 20,000 yr] resulting from all scenario classes were observed (i.e., compare the results in Figures K8.1-1 and K8.1-2 with the results in Figures K8.1-1[a] and K8.1-2[a]). The similarity in expected dose to the RMEI results from the similarity in the results of the Seismic Ground Motion Scenario Class. Additional comparisons are presented in Figures 7.3.1-42[a] and 7.3.1-43[a] and discussed in Section 7.3.1.5.8[a].

For reader convenience, the following discussion of the expected dose results in Figures K8.1-1[a] and K8.1-2[a] is provided. This discussion updates the corresponding material in Section K8.1 from the parent report.

The uncertainty and sensitivity analyses for expected dose to the RMEI (EXPDOSE, mrem/yr) over the time interval [0, 20,000 yr] resulting from all scenario classes are summarized in Figures K8.1-1[a] and K8.1-2[a]. Initial transport to the location of the RMEI takes up to 2000 yr; after the earliest possible arrival time for released radionuclides at the location of the RMEI, EXPDOSE increases monotonically with time (Figure K8.1-1a,b[a]). At 10,000 yr, the value for EXPDOSE falls between $10^{-3}$ and 4 mrem/yr. As indicated by Figure 8.1-3a[a], the expected dose to the RMEI from all scenario classes is predominantly determined by the
expected dose to the RMEI resulting from seismic ground motion and igneous intrusion. However, for some sample elements, minor effects from early WP failures can be observed in Figure K8.1-1b[a], where the initiation of transport from CNSF WPs after 9000 yr produces spikes in the expected dose. In turn, these spikes result in minor variability in the PRCCs (Figure K8.1-1c[a]).

The PRCCs in Figure K8.1-1c[a] indicate that the four most important variables with respect to the uncertainty in EXPDOSE over the time interval [0, 20,000 yr] are SCCTHRP (residual stress threshold; as sampled, SCCTHRP is a percent of a base value of 351 MPa and is related to the stress corrosion cracking threshold, SCCTHR, by SCCTHRP = (SCCTHR × 100)/(351 MPa)), IGRATE (rate of occurrence of igneous intrusive events, yr\(^{-1}\)), SZGWSPDM (groundwater specific discharge multiplier; as sampled, SZGWSPDM is actually the logarithm of the indicated multiplier), and MICC14 (dose conversion factor for \(^{14}\)C for modern interglacial climate, (rem/yr)/(pCi/L)). The negative effect associated with SCCTHRP results because increasing SCCTHRP results in WPs being more resistant to seismic ground motion damage; the positive effect associated with IGRATE results because increasing IGRATE increases the probability of occurrence for igneous events; the positive effect associated with SZGWSPDM results because increasing SZGWSPDM increases water flow in the SZ; and the positive effect associated with MICC14 results from increasing the dose that results from a given exposure to \(^{14}\)C (and probably other radionuclides as a result of positive correlations involving dose factors). As indicated by the size of the PRCCs, SCCTHRP is the most important of these four variables.

After SCCTHRP, IGRATE, SZGWSPDM and MICC14, smaller effects are indicated for SZFIPOVO (flowing interval porosity in the volcanic unit of the SZ) and INFIL (infiltration level) (Figure K8.1-1c[a]) before about 5,000 years. The negative effect associated with SZFIPOVO at early times results from initially slowing the movement of radioactive species in the SZ, and the positive effect associated with INFIL results from its role in both speeding the cooling of the repository and increasing water flow in the EBS and UZ.

More detailed sensitivity analyses for EXPDOSE are provided by the regression analyses and associated scatterplots in Figure K8.1-2[a]. Overall, the dominant variable with respect to the uncertainty in EXPDOSE is SCCTHRP. Specifically, the regressions containing only SCCTHRP have \(R^2\) values of 0.55, 0.66 and 0.69 at 3000, 5000 and 10,000 yr, respectively (Figure K8.1-2a[a]). After SCCTHRP, the next variable selected in all regressions is IGRATE, with the inclusion of IGRATE raising the cumulative \(R^2\) values to 0.62, 0.71 and 0.73. Thus, the effect of IGRATE on EXPDOSE is not as great as the effect of SCCTHRP. In consistency with the analysis with PRCCs, SZGWSPDM is then the third variable selected in the three regressions analyses. The negative effect associated with SCCTHRP and the positive effects associated with IGRATE and SZGWSPDM can be seen in the scatterplots in Figure K8.1-2a,b,c[a]. After SCCTHRP, IGRATE and SZGWSPDM, the regressions select a number of additional variables that have small effects on EXPDOSE. The final regression models have \(R^2\) values of 0.81, 0.85 and 0.82, which indicates that they are reasonably successful in accounting for the uncertainty in EXPDOSE. However, as is always the case, some of the variables selected at the ends of individual regression analyses that have very small effects on cumulative \(R^2\) values may be spurious.
It is important to recognize that the results in Figures K8.1-1[a] and K8.1-2[a] reflect the sensitivity of EXPDOSE for the 20,000-yr time period to those parameters that are treated as being uncertain in the TSPA-LA Model. Where parameters and model inputs are not treated as being uncertain, but are instead represented by conservative, fixed values or by assumptions, the sensitivity of EXPDOSE to these parameters can be discussed qualitatively but cannot be quantified. For example, significant uncertainty is associated with the definition of the seismic hazard curve that underlies the occurrence of seismic events and the effects of seismic events. If the uncertainty associated with the seismic hazard curve was incorporated into the analysis, it is likely that this uncertainty would have an effect on the uncertainty associated with EXPDOSE.

K8.2[a] All Scenario Classes: Expected Dose (EXPDOSE) to Reasonably Maximally Exposed Individual (RMEI) over the Time Interval [0, 1,000,000 yr]

Because of the changes to the Seismic Ground Motion Scenario Class (Appendix P, Section P3), and the importance of this scenario class to the total expected dose (Figure 8.1-3[a]), the changes to the Seismic Ground Motion Scenario Class affect the uncertainty and sensitivity analyses for expected dose to the RMEI (EXPDOSE, mrem/yr) over the time interval [0, 1,000,000 yr]. As discussed in Section K7.7.2[a], the change to the models for estimating damage from seismic events, as described in Appendix P, Section P3, alters the relationships between input and output variables. The most significant effect of the model changes is to flatten the peak in the expected (mean) dose that occurs around 230,000 years (compare Figure 8.1-2 and Figure 8.1-2[a]). As a consequence, the input variables identified as important at 200,000 yr and at 252,000 yr are different for the two model versions. However, at earlier and at later times, the sensitivity analyses for both model versions agree on the three most important variables but showed considerable disagreement on less important variables (i.e., compare the results in Figures K8.2-1 and K8.2-2 with the results in Figures K8.2-1[a] and K8.2-2[a]). Additional comparisons are presented in Figures 7.3.1-45[a] and 7.3.1-46[a] and discussed in Section 7.3.1.5.9[a].

For reader convenience, the following discussion of the expected dose results in Figures K8.2-1[a] and K8.2-2[a] is provided. This discussion updates the corresponding material in Section K8.2 from the parent report.

The uncertainty and sensitivity analyses for expected dose to the RMEI (EXPDOSE, mrem/yr) over the time interval [0, 1,000,000 yr] resulting from all scenario classes are summarized in Figures K8.2-1[a] and K8.2-2[a]. As indicated by Figure 8.1-3b[a], the expected dose to the RMEI from all scenario classes is predominantly determined by the expected dose to the RMEI resulting from seismic ground motion and from igneous intrusion.

The time-dependent values for EXPDOSE appear somewhat choppy as a result of the sampling-based effects of nominal processes and seismic ground motion events (Figure K7.7.2-1[a]). Smoother results could be obtained by using a larger sample of aleatory futures for seismic ground motion events or possibly a more sophisticated integration procedure for the incorporation of such events. However, because the distribution of EXPDOSE has been shown to be statistically stable (Section 7.3.1.3 and Section 7.3.1.5.9[a]), improved convergence or use of a better integration procedure would produce smoother estimates of expected dose, but
would not produce results that differ substantially from those shown in Figure K8.2-1[a]. The values for EXPDOSE fall in a range from $10^{-4}$ to 40 mrem/yr.

The PRCCs in Figure K8.2-1c[a] indicate that the three most important variables with respect to the uncertainty in EXPDOSE are SCCTHRP (residual stress threshold; as sampled, SCCTHRP is a percent of a base value of 351 MPa and is related to the stress corrosion cracking threshold, SCCTHR, by $SCCTHRP = (SCCTHR \times 100)/(351 \text{ MPa})$), IGRATE (rate of occurrence of igneous intrusive events, yr$^{-1}$), SZGWSPDM (groundwater specific discharge multiplier; as sampled, SZGWSPDM is actually the logarithm of the indicated multiplier), and WDGCA22 (temperature dependence coefficient associated with the general corrosion rate for Alloy 22, K). The negative effect associated with SCCTHRP results because increasing SCCTHRP increases the resistance of WPs to seismic ground motion damage; the positive effect associated with IGRATE results because increasing IGRATE increases the probability of occurrence for igneous events; the positive effect associated with SZGWSPDM results because increasing SZGWSPDM increases water flow in the SZ; and the negative effect associated with WDGCA22 results from its role in slowing the rate of general corrosion of Alloy 22, which in turn delays and reduces WP failures due to both seismic ground motion events and general corrosion.

Smaller effects are indicated for SZFIPOVO (flowing interval porosity in the volcanic unit of the SZ) and EP1LOWPU (scale factor used to incorporate uncertainty into plutonium solubility under low ionic strength conditions; as sampled, EP1LOWPU is actually the logarithm of the indicated scale factor). The negative effect of SZFIPOVO only occurs at very early times (Figure K8.1-1c[a]) and results from increasing the time required for an initial radionuclide release into the SZ to reach the RMEI. The positive effect of EP1LOWPU results from increasing the amount of dissolved plutonium that is released from the EBS.

More detailed sensitivity analysis results are provided by the regression analyses and associated scatterplots in Figure K8.2-2[a]. At 50,000 yr, the most important variable is SCCTHRP, which results in a single-variable regression model with an $R^2$ value of 0.27. At 200,000 and 500,000 yr, the most important variable is IGRATE, which results in single-variable regression models with $R^2$ values of 0.38 and 0.29. Further, IGRATE is the second variable selected at 50,000 yr. After these initial selections, the stepwise analyses continue and construct models with 9, 16 and 13 variables and corresponding $R^2$ values of 0.67, 0.74 and 0.70. Thus, a large number of variables are affecting uncertainty in EXPDOSE over 1,000,000 yr with no single variable dominating this uncertainty. For perspective, the effects of IGRATE, WDGCA22 and SZGWSPDM on EXPDOSE at 500,000 yr can be seen in the scatterplots in Figure K8.2-2b,c,d[a].

As previously indicated in conjunction with Figures K8.1-1[a] and K8.1-2[a] for the 20,000-yr time period, it is important to recognize that the results in Figures K8.2-1[a] and K8.2-2[a] reflect the sensitivity of EXPDOSE for the 1,000,000 yr time period to those parameters that are treated as being uncertain in the TSPA-LA Model. Some important parameters and model inputs are not treated as being uncertain, but are instead represented by conservative, fixed values or by assumptions. In particular, if the uncertainty associated with the seismic hazard curve was incorporated into the analysis, it is likely that this uncertainty would have an effect on the uncertainty associated with EXPDOSE.
K9[a] SUMMARY

This addendum updates uncertainty and sensitivity analyses for expected dose to the RMEI reported in Appendix K with results obtained from TSPA-LA Model v5.005. In addition, for the Igneous Intrusion Scenario Classes, this addendum reports new uncertainty and sensitivity analyses for the movement of $^{234}$U, $^{230}$Th, and $^{226}$Ra out of the EBS, UZ and SZ, as well as dose to the RMEI for these radionuclides. Comparison of the results of the uncertainty and sensitivity analyses for the two TSPA-LA Model versions shows that the two models produce similar results, although some differences in results can be observed for the Seismic Ground Motion Scenario Class, and for a few sample elements in most scenario classes. Due to the similarity evident in the results from the two models, the analyses presented in Appendix K for the movement of representative radionuclides ($^{239}$Pu, $^{237}$Np, and $^{99}$Tc) are not repeated; conclusions from these analyses apply equally to TSPA-LA Model v5.005.

Table K9-1[a] summarizes sensitivity analysis results for total expected dose and expected dose by scenario class by listing the key uncertain inputs identified by the analysis, using results from TSPA-LA Model v5.005. The key uncertain inputs in Table K9-1[a] are listed in decreasing order of importance with the first listed input having the most effect on the output quantity. The key uncertain inputs are identified on the basis of sensitivity analysis results at roughly the time the mean of the output variable achieves its maximum value. Table K9-1[a] and Table K9-1 generally show the same key uncertain inputs for each scenario class, but there are exceptions. The changes to the Seismic Ground Motion Scenario Class for TSPA-LA Model v5.005 caused the maximum of the expected (mean) dose for this scenario class as well as for total expected (mean) dose to move from 230,000 yr to 1,000,000 yr. Consequently, the key uncertain inputs for these two output variables are different. Additionally, the third or fourth uncertain inputs for some scenario classes have changed due to other corrections to the TSPA-LA Model.

Generally, the uncertain inputs that predominantly determine uncertainty in expected dose for each scenario class are those inputs that describe the occurrence and extent of failure of EBS components. This conclusion is the same for both model versions. For the Seismic Ground Motion Scenario Class, the key uncertain input at early times is $SCCTHRP$ (residual stress threshold; as sampled, $SCCTHRP$ is a percent of a base value of 351 MPa and is related to the stress corrosion cracking threshold, $SCCTHR$, by $SCCTHRP = (SCCTHR \times 100)/(351 \text{ MPa})$), which essentially determines the probability of damage to CDSP or CSNF WPs for each seismic event. At later times, because the Seismic Ground Motion Scenario Class is combined with the Nominal Scenario Class, the key uncertain input is $WDGCA22$ (temperature dependence coefficient associated with general corrosion rate for Alloy 22, K), which essentially determines the uncertainty in the time and extent of general corrosion failures (both by stress-corrosion cracking and by patches). For the Igneous Intrusive Scenario Class, the key uncertain input is $IGRATE$ (rate of occurrence of igneous intrusive events, $\text{yr}^{-1}$). For the Nominal Scenario Class the key uncertain input is $WDGCA22$ (temperature dependence coefficient associated with general corrosion rate for Alloy 22, K), which essentially determines the uncertainty in the time and extent of general corrosion failures (both by SCC and by patches). For the Early Failure Scenario Classes key uncertain inputs are $PROBWPEF$ (probability that a randomly selected WP will experience an early failure) and $PROBDSEF$ (probability that a randomly selected DS will experience an early failure). For the Igneous Eruptive Scenario Class the key uncertain input is $IGRATE$ (rate of occurrence of volcanic eruption events, $\text{yr}^{-1}$). For the Seismic Fault
Displacement Modeling Case, no single input emerged as predominant. Rather, the analysis identified several uncertain inputs with moderately monotonic effects on the expected dose for the scenario class.
Table K9-1[a]. Summary of Selected Sensitivity Analysis Results

<table>
<thead>
<tr>
<th>Scenario Class</th>
<th>TSPA-LA Model Output (time of maximum mean value)</th>
<th>Key Uncertain Inputs¹</th>
</tr>
</thead>
</table>
| **Total System** | **Total expected dose 0 to 10,000 years (10,000 years)** | • Residual stress threshold for SCC (SCCTHRP)  
• Frequency of occurrence of igneous events (IGRATE)  
• Logarithm of scale factor in ground water specific discharge (SZGWSPOD) |
| **Total System** | **Total expected dose 10,000 to 1,000,000 years (1,000,000 years)** | • Frequency of occurrence of igneous events (IGRATE)  
• General corrosion rate (Alloy 22) temperature dependence (WDGCA22)  
• Logarithm of scale factor in ground water specific discharge (SZGWSPOD) |
| **Nominal** | **Expected dose resulting from corrosion processes (720,000 years)** | • General corrosion rate (Alloy 22) temperature dependence (WDGCA22)  
• Deviation from median yield strength range for outer lid (WDZOLID) |
| **Early Failure** | **Expected dose resulting from early failure of drip shields over 20,000 years (2,000 years)** | • Probability of early failure per drip shield (PROBDSEF)  
• Uncertainty factor accounting for small-scale heterogeneity in fracture permeability (SEEUNC)  
• Logarithm of mean fracture permeability in lithophysal rock units (SEEPRM) |
| **Early Failure** | **Expected dose resulting from early failure of waste packages over 20,000 years (12,000 years)** | • Probability of early failure per waste package (PROBWPEF)  
• Pointer variable for infiltration scenario (INFIL)  
• Selector for host-rock thermal conductivity scenario (THERMCON) |
| **Igneous** | **Expected dose resulting from igneous intrusion over 20,000 years (20,000 years)** | • Frequency of occurrence of igneous events (IGRATE)  
• Logarithm of scale factor in ground water specific discharge (SZGWSPOD)  
• Pointer variable for infiltration scenario (INFIL) |
| **Igneous** | **Expected dose resulting from igneous intrusion over 1,000,000 years (1,000,000 years)** | • Frequency of occurrence of igneous events (IGRATE)  
• Logarithm of scale factor in ground water specific discharge (SZGWSPOD)  
• Pointer variable for infiltration scenario (INFIL) |
| **Igneous** | **Expected dose resulting from volcanic eruption over 20,000 years (20,000 years)** | • Frequency of occurrence of volcanic eruptions (IGERATE)  
• Pointer variable for long-term inhalation dose conversation factors for exposure to volcanic ash (INHLTPV)  
• Diffusivity of radionuclides in divides (DDIVIDE) |
| **Igneous** | **Expected dose resulting from volcanic eruption over 1,000,000 years (1,000,000 years)** | • Frequency of occurrence of volcanic eruptions (IGERATE)  
• Depth of soil within which radionuclides affect the biosphere (BTILLAGE) |
Table K9-1[a]. Summary of Selected Sensitivity Analysis Results (Continued)

<table>
<thead>
<tr>
<th>Scenario Class</th>
<th>TSPA-LA Model Output (time of maximum mean value)</th>
<th>Key Uncertain Inputs&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seismic Ground Motion</td>
<td>Expected dose resulting from seismic ground motion over 20,000 years (20,000 years)</td>
<td>• Residual stress threshold for SCC (SCCTHRP)</td>
</tr>
<tr>
<td></td>
<td>Expected dose resulting from combination of seismic ground motion and corrosion processes over 1,000,000 years (1,000,000 years)</td>
<td>• General corrosion rate (Alloy 22) temperature dependence (WDGCA22) • Residual stress threshold (SCCTHRP)</td>
</tr>
<tr>
<td>Seismic Fault Displacement</td>
<td>Expected dose resulting from fault displacement over 20,000 years (20,000 years)</td>
<td>• Groundwater biosphere dose conversion factor for 99Tc (MICTC99) • Pointer variable for infiltration scenario (INFIL) • Logarithm of scale factor in ground water specific discharge (SZGWSPDM) • Selector variable determining the collapsed drift rubble thermal conductivity (DTDRHUNC)</td>
</tr>
<tr>
<td></td>
<td>Expected dose resulting from fault displacement over 1,000,000 years (1,000,000 years)</td>
<td>• Pointer variable for infiltration scenario (INFIL) • Logarithm of scale factor for uncertainty in plutonium solubility at ionic strength below 1 molal (EP1LOWPU) • Logarithm of scale factor in ground water specific discharge (SZGWSPDM) • Waste package flux splitting factor (WPFLUX)</td>
</tr>
</tbody>
</table>

<sup>a</sup> Name (in parentheses) is the variable name used in the sensitivity analyses (see Table K3-1).
**K10[a] HUMAN INTRUSION SCENARIO**

Uncertainty and sensitivity analysis results for human intrusion at 200,000 yr are presented in two sets. The first set is for expected dose to the RMEI \((EXPDOSE, \text{mrem/yr})\) over the time period \([200,000, 220,000 \text{ yr}]\) (Figures K10-1[a] and K10-2[a]); the second set is for expected dose to the RMEI \((EXPDOSE, \text{mrem/yr})\) over the time period \([220,000, 1,000,000 \text{ yr}]\) (Figures K10-3[a] and K10-4[a]). This division is made because of the rapid changes in \(EXPDOSE\) that occur in the first 20,000 yr after a drilling intrusion. This analysis is reported separately from the other scenario classes because the human intrusion results are calculated for comparison with the human intrusion standard. In contrast, the preceding analyses for expected dose to the RMEI are calculated for comparison with the individual protection standard.

As examination of Figure K10-1a,b[a] shows, \(EXPDOSE\) increases rapidly for the first 1000 to 2000 yr after a drilling intrusion at 200,000 yr and then decreases monotonically out to 220,000 yr. The individual sample elements produce peak values for \(EXPDOSE\) between approximately 0.003 and 0.1 mrem/yr; at 220,000 yr the values for \(EXPDOSE\) are between 0.00006 and 0.02 mrem/yr. The monotonic decrease in \(EXPDOSE\) can be seen in Figure K10-3a,b[a] to continue out to approximately 400,000 yr; beyond 400,000 yr, \(EXPDOSE\) remains approximately constant with a slight tendency to increase.

For the time period \([200,000, 300,000 \text{ yr}]\), \(^{99}\text{Tc}\) and \(^{129}\text{I}\) are the dominant radionuclides contributing to \(EXPDOSE\); for the time period \([300,000, 1,000,000 \text{ yr}]\), \(^{242}\text{Pu}\) is the dominant radionuclide contributing to \(EXPDOSE\) (Figure 8.1-17[a]).

Sensitivity analysis results for the \([200,000, 220,000 \text{ yr}]\) time period are presented in Figures K10-1c[a] and K10-2b,c,d,e,f,g[a]. As indicated by the PRCCs in Figure K10-1c[a], the most important variables affecting \(EXPDOSE\) for the first 5000 yr after the intrusion are \(INFIL\) (infiltration level), \(CSSPECSA\) (effective specific surface area of CSNF waste, \(\text{m}^2/\text{mg}\); as sampled, \(CSSPECSA\) is actually the logarithm of the indicated surface area), \(SZGWSPDM\) (groundwater specific discharge multiplier; as sampled, \(SZGWSPDM\) is actually the logarithm of the indicated multiplier), \(SZFIPOVO\) (flowing interval porosity in the volcanic unit of the SZ), \(MICTC99\) (dose conversion factor for \(^{99}\text{Tc}\) for modern interglacial climate, \((\text{rem/yr})/(\text{pCi/L})\)), and \(EBSDIFCF\) (scale factor used to represent uncertainty in EBS diffusion coefficient; as sampled, \(EBSDIFCF\) is actually the logarithm of the indicated scale factor). For the first 5000 yr after the intrusion, \(INFIL\), \(CSSPECSA\), \(SZGWSPDM\), \(MICTC99\) and \(EBSDIFCF\) have positive effects on \(EXPDOSE\), and \(SZFIPOVO\) has a negative effect on \(EXPDOSE\). These effects result because (1) increasing \(INFIL\) increases water flow in the EBS and UZ, (2) increasing \(CSSPECSA\) increases the release of radionuclides from degrading CSNF waste, (3) increasing \(SZGWSPDM\) increases water movement in the SZ, (4) increasing \(MICTC99\) increases the dose received from a unit concentration of \(^{99}\text{Tc}\) in groundwater, and (5) increasing \(EBSDIFCF\) increases the release of radionuclides from the EBS. In contrast, increasing \(SZFIPOVO\) has an early negative effect on \(EXPDOSE\) as a result of increasing the volume of water involved in radionuclide transport in the SZ; however, this dilution effect is short lived and quickly ceases as more radionuclides enter the SZ.

After approximately 5000 yr, \(INFIL\), \(CSSPECSA\), \(SZGWSPDM\) and \(EBSDIFCF\) have a negative effect on \(EXPDOSE\) (Figure K10-1c[a]). This reversal in effects results from the high mobility...
of $^{99}$Tc and $^{129}$I, which are the dominant radionuclides contributing to $EXPDOSE$ prior to 300,000 yr. Because of this mobility, variables that increase the release of $^{99}$Tc and $^{129}$I at early times (i.e., in the first 5000 yr after intrusion) also decrease the releases of $^{99}$Tc and $^{129}$I at later times. As a result, INFIL, CSSPECSA, SZGWSPDM and EBSDIFCF have a positive effect on $EXPDOSE$ in the first 5000 yr after intrusion and a negative effect on $EXPDOSE$ at later times. In contrast, MICTC99 continues to have a positive effect on $EXPDOSE$ with increasing time.

More detailed analyses for $EXPDOSE$ for the time period [200,000, 205,000 yr] are provided by the stepwise regression analyses and scatterplots in Figure K10-2[a]. As examination of the regression analyses and associated scatterplots shows, many individual variables affect $EXPDOSE$ with no single variable having a dominant effect on the uncertainty in $EXPDOSE$. Further, many variables having small effects and possibly some complex interactions between variables and the radionuclides that they affect, results in regression models with small $R^2$ values (i.e., 0.75, 0.53 and 0.41).

As indicated by the PRCCS in Figure K10-3c[a], the most important variables affecting $EXPDOSE$ after approximately 300,000 yr are SZGWSPDM, GOESITED (density of sorption sites on goethite, sites/nm$^2$), COLFEOSS (iron oxide colloid concentration when degraded stainless steel is present but no degrading carbon steel is present, mg/L), EP1LOWPU (scale factor used to incorporate uncertainty into plutonium solubility under low ionic strength conditions; as sampled, $EP1LOWPU$ is actually the logarithm of the indicated scale factor), and SZFISPVO (flowing interval spacing in volcanic unit of SZ, m). The variables SZGWSPDM, COLFEOSS, $EP1LOWPU$ and SZFISPVO have positive effects on $EXPDOSE$; in contrast, GOESITED has a negative effect. The positive effects associated with SZGWSPDM, COLFEOSS, $EP1LOWPU$ and SZFISPVO result because (1) increasing SZGWSPDM increases water flow in the SZ, (2) increasing COLFEOSS increases the attachment of radionuclides to mobile colloids, (3) increasing $EP1LOWPU$ increases the solubility of plutonium, and (4) increasing SZFISPVO decreases the diffusion of radionuclides from fractures in the volcanic unit of the SZ into the surrounding rock matrix. The negative effect associated with GOESITED results from increasing the sorption of radionuclides onto corrosion products in the EBS.

More detailed analyses for $EXPDOSE$ for the time period [220,000, 1,000,000 yr] are provided by the stepwise regression analyses and scatterplots in Figure K10-4[a]. As examination of the regression analyses and associated scatterplots shows, many individual variables affect $EXPDOSE$ with no single variable having a dominant effect on the uncertainty in $EXPDOSE$. Further, many variables having small effects and possibly some complex interactions between variables and the radionuclides that they affect is resulting in regression models with small $R^2$ values (i.e., 0.50, 0.55, and 0.63).

Comparisons of results for $EXPDOSE$ resulting from human intrusion at 200,000 yr obtained with versions 5.000 and 5.005 of the TSPA-LA Model are presented in Figures K10-5[a] and K10-6[a].
Figure K4.5-1[a]. Dose to RMEI (DOSTOT, mrem/yr) for all radioactive species under nominal conditions obtained with version 5.005 of the TSPA-LA Model: (a) DOSTOT for all (i.e., 300) sample elements, (b) DOSTOT for first 50 sample elements, (c) PRCCs for DOSTOT for [0; 1,000,000 yr], and (d) PRCCs for DOSTOT for [200,000; 1,000,000 yr]
Figure K4.5-2[a]. Stepwise rank regression analyses and selected scatterplots for dose to RMEI ($DOSTOT$, mrem/yr) for all radioactive species under nominal conditions obtained with version 5.005 of the TSPA-LA Model: (a) regressions for $DOSTOT$ at 400,000, 600,000, and 800,000 years, and (b,c,d) scatterplots for $DOSTOT$ at 600,000 years.
Figure K5.7.1-1[a]. Expected dose to RMEI ($EXPDOSE$, mrem/yr) over [0, 20,000 yr] for all radioactive species resulting from early DS failure obtained with version 5.005 of the TSPA-LA Model: (a) $EXPDOSE$ for all (i.e., 300) sample elements, (b) $EXPDOSE$ for first 50 sample elements, and (c) PRCCs for $EXPDOSE$
Figure K5.7.1-2[a]. Stepwise rank regression analyses and selected scatterplots for expected dose to RMEI (EXPDOSE, mrem/yr) over [0, 20,000 yr] for all radioactive species resulting from early DS failure obtained with version 5.005 of the TSPA-LA Model: (a) regressions for EXPDOSE at 3,000, 5,000, and 10,000 years, and (b,c,d) scatterplots for EXPDOSE at 10,000 years.

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MOO710PLOTSFIG.000 [DIRS 185207].

NOTE: In (c), the box extends from 0.25 to 0.75 quantile; lower and upper bar and whisker extend to 0.1 and 0.9 quantile, respectively; dots represent values outside 0.1 to 0.9 quantile range; median indicated by light horizontal line.
Figure K5.7.1-3[a]. Expected dose to RMEI (\textit{EXPDOSE}, mrem/yr) over [0, 1,000,000 yr] for all radioactive species resulting from early DS failure obtained with version 5.005 of the TSPA-LA Model: (a) \textit{EXPDOSE} for all (i.e., 300) sample elements, (b) \textit{EXPDOSE} for first 50 sample elements, and (c) PRCCs for \textit{EXPDOSE}. 

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0710PLOTSFIG.000 [DIRS 185207].
Figure K5.7.1-4[a]. Stepwise rank regression analyses and selected scatterplots for expected dose to RMEI (EXPDOSE, mrem/yr) over [0, 1,000,000 yr] for all radioactive species resulting from early DS failure obtained with version 5.005 of the TSPA-LA Model: (a) regressions for EXPDOSE at 50,000, 200,000, and 500,000 years, and (b,c,d) scatterplots for EXPDOSE at 500,000 years.

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0710PLOTSFIG.000 [DIRS 185207].

NOTE: In (c), the box extends from 0.25 to 0.75 quantile; lower and upper bar and whisker extend to 0.1 and 0.9 quantile, respectively; dots represent values outside 0.1 to 0.9 quantile range; median indicated by light horizontal line.
Figure K5.7.2-1[a]. Expected dose to RMEI (EXPDOSE, mrem/yr) over [0, 20,000 yr] for all radioactive species resulting from early WP failure obtained with version 5.005 of the TSPA-LA Model: (a) EXPDOSE for all (i.e., 300) sample elements, (b) EXPDOSE for first 50 sample elements, and (c) PRCCs for EXPDOSE.
Figure K5.7.2-2[a]. Stepwise rank regression analyses and selected scatterplots for expected dose to RMEI (EXPDOSE, mrem/yr) over [0, 20,000 yr] for all radioactive species resulting from early WP failure obtained with version 5.005 of the TSPA-LA Model: (a) regressions for EXPDOSE at 3,000, 5,000, and 10,000 years, and (b,c,d) scatterplots for EXPDOSE at 10,000 years.
Figure K5.7.2-3[a]. Expected dose to RMEI (\textit{EXPDOSE}, mrem/yr) over [0, 1,000,000 yr] for all radioactive species resulting from early WP failure obtained with version 5.005 of the TSPA-LA Model: (a) \textit{EXPDOSE} for all (i.e., 300) sample elements, (b) \textit{EXPDOSE} for first 50 sample elements, and (c) PRCCs for \textit{EXPDOSE}
Figure K5.7.2-4[a]. Stepwise rank regression analyses and selected scatterplots for expected dose to RMEI (EXPDOSE, mrem/yr) over [0, 1,000,000 yr] for all radioactive species resulting from early WP failure obtained with version 5.005 of the TSPA-LA Model: (a) regressions for EXPDOSE at 50,000, 200,000, and 500,000 years, and (b,c,d) scatterplots for EXPDOSE at 500,000 years.

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0710PLOTSFIG.000 [DIRS 185207].

NOTE: In (c), the box extends from 0.25 to 0.75 quantile; lower and upper bar and whisker extend to 0.1 and 0.9 quantile, respectively; dots represent values outside 0.1 to 0.9 quantile range; median indicated by light horizontal line.
Figure K6.3.2-5[a]. Time-dependent release rates ($ESU234$, g/yr) and cumulative (i.e., integrated) releases ($ESU234C$, g) over 1,000,000 years for the movement of dissolved $^{234}$U from the EBS to the UZ resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository obtained with version 5.005 of the TSPA-LA Model: (a,b) $ESU234$ and $ESU234C$ for all (i.e., 300) sample elements, (c,d) $ESU234$ and $ESU234C$ for first 50 sample elements, and (e,f) PRCCs for $ESU234$ and $ESU234C$.

Source: Output DTNs: MO0801TSPAPRSA.000 [DIRS 184620]; and MO0710PLOTSFIG.000 [DIRS 185207].
### Figure K6.3.2-6[a]

Stepwise rank regression analyses and selected scatterplots for time-dependent release rates (ESU234, g/yr) and cumulative (i.e., integrated) releases (ESU234C, g) for the movement of dissolved \(^{234}\text{U}\) from the EBS to the UZ resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository obtained with version 5.005 of the TSPA-LA Model: (a,b) regressions for ESU234 and ESU234C at 50,000, 200,000, and 500,000 years, and (c-h) scatterplots for ESU234 and ESU234C at 500,000 years.

#### Table 1

<table>
<thead>
<tr>
<th>Step</th>
<th>Variable</th>
<th>ESU234: 50,000 Years</th>
<th>ESU234: 200,000 Years</th>
<th>ESU234: 500,000 Years</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(R^2)</td>
<td>SRRC</td>
<td>(R^2)</td>
</tr>
<tr>
<td>1</td>
<td>EP1LOWOU</td>
<td>0.38</td>
<td>0.56</td>
<td>0.41</td>
</tr>
<tr>
<td>2</td>
<td>INFIL</td>
<td>0.49</td>
<td>0.33</td>
<td>0.58</td>
</tr>
<tr>
<td>3</td>
<td>GOESITED</td>
<td>0.57</td>
<td>-0.29</td>
<td>0.66</td>
</tr>
<tr>
<td>4</td>
<td>CORRATSS</td>
<td>0.64</td>
<td>-0.30</td>
<td>0.70</td>
</tr>
<tr>
<td>5</td>
<td>HFOSA</td>
<td>0.67</td>
<td>-0.19</td>
<td>0.73</td>
</tr>
<tr>
<td>6</td>
<td>GOERELAB</td>
<td>0.69</td>
<td>0.12</td>
<td>0.75</td>
</tr>
<tr>
<td>7</td>
<td>DSNFMASS</td>
<td>0.71</td>
<td>0.12</td>
<td>0.76</td>
</tr>
<tr>
<td>8</td>
<td>PHCSS</td>
<td>0.72</td>
<td>0.16</td>
<td>0.77</td>
</tr>
<tr>
<td>9</td>
<td>IS2MCOS</td>
<td>0.74</td>
<td>0.13</td>
<td>0.77</td>
</tr>
<tr>
<td>10</td>
<td>CSNFMASS</td>
<td>0.75</td>
<td>0.12</td>
<td>0.78</td>
</tr>
<tr>
<td>11</td>
<td>KDPUCOL</td>
<td>0.76</td>
<td>0.09</td>
<td>0.79</td>
</tr>
<tr>
<td>12</td>
<td>GOESA</td>
<td>0.77</td>
<td>-0.08</td>
<td>0.79</td>
</tr>
<tr>
<td>13</td>
<td>DELPPCO2</td>
<td>0.76</td>
<td>0.08</td>
<td></td>
</tr>
</tbody>
</table>

#### Table 2

<table>
<thead>
<tr>
<th>Step</th>
<th>Variable</th>
<th>ESU234C: 50,000 Years</th>
<th>ESU234C: 200,000 Years</th>
<th>ESU234C: 500,000 Years</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(R^2)</td>
<td>SRRC</td>
<td>(R^2)</td>
</tr>
<tr>
<td>1</td>
<td>EP1LOWOU</td>
<td>0.37</td>
<td>0.56</td>
<td>0.40</td>
</tr>
<tr>
<td>2</td>
<td>INFIL</td>
<td>0.48</td>
<td>0.34</td>
<td>0.53</td>
</tr>
<tr>
<td>3</td>
<td>GOESITED</td>
<td>0.56</td>
<td>-0.29</td>
<td>0.62</td>
</tr>
<tr>
<td>4</td>
<td>CORRATSS</td>
<td>0.60</td>
<td>-0.25</td>
<td>0.65</td>
</tr>
<tr>
<td>5</td>
<td>PHCSS</td>
<td>0.63</td>
<td>0.19</td>
<td>0.68</td>
</tr>
<tr>
<td>6</td>
<td>IS2MCOS</td>
<td>0.65</td>
<td>0.16</td>
<td>0.71</td>
</tr>
<tr>
<td>7</td>
<td>HFOSA</td>
<td>0.67</td>
<td>-0.17</td>
<td>0.73</td>
</tr>
<tr>
<td>8</td>
<td>DELPPCO2</td>
<td>0.69</td>
<td>0.12</td>
<td>0.74</td>
</tr>
<tr>
<td>9</td>
<td>CSNFMASS</td>
<td>0.70</td>
<td>0.14</td>
<td>0.75</td>
</tr>
<tr>
<td>10</td>
<td>GOERELAB</td>
<td>0.71</td>
<td>0.11</td>
<td>0.76</td>
</tr>
<tr>
<td>11</td>
<td>GOESA</td>
<td>0.72</td>
<td>-0.09</td>
<td>0.77</td>
</tr>
<tr>
<td>12</td>
<td>DSNFMASS</td>
<td>0.73</td>
<td>0.09</td>
<td>IS2MCOS</td>
</tr>
<tr>
<td>13</td>
<td>CPUERCS</td>
<td>0.74</td>
<td>-0.08</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>RHUNM40</td>
<td>0.75</td>
<td>-0.08</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>KDPUCOL</td>
<td>0.75</td>
<td>0.08</td>
<td></td>
</tr>
</tbody>
</table>

---

Source: Output DTNs: MO0801TSPAPRSA.000 [DIRS 184620]; and MO0710PLOTSFIG.000 [DIRS 185207].
Source: Output DTNs: MO0801TSPAPRSA.000 [DIRS 184620]; and MO0710PLOTSFIG.000 [DIRS 185207].

NOTE: In (d,g), the box extends from 0.25 to 0.75 quantile; lower and upper bar and whisker extend to 0.1 and 0.9 quantile, respectively; dots represent values outside 0.1 to 0.9 quantile range; median indicated by light horizontal line.

Figure K6.3.2-6[a]. Stepwise rank regression analyses and selected scatterplots for time-dependent release rates ($ESU234$, g/yr) and cumulative (i.e., integrated) releases ($ESU234C$, g) for the movement of dissolved $^{234}U$ from the EBS to the UZ resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository obtained with version 5.00 of the TSPA-LA Model: (a,b) regressions for $ESU234$ and $ESU234C$ at 50,000, 200,000, and 500,000 years, and (c-h) scatterplots for $ESU234$ and $ESU234C$ at 500,000 years (continued)
Total System Performance Assessment Model/Analysis for the License Application

Source: Output DTNs: MO0801TSPAPRSA.000 [DIRS 184620]; and MO0710PLOTSFIG.000 [DIRS 185207].

Figure K6.3.2-7[a]. Time-dependent release rates (ESTH230, g/yr) and cumulative (i.e., integrated) releases (ESTH230C, g) over 1,000,000 years for the movement of dissolved 230Th from the EBS to the UZ resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository obtained with version 5.005 of the TSPA-LA Model: (a,b) ESTH230 and ESTH230C for all (i.e., 300) sample elements, (c,d) ESTH230 and ESTH230C for first 50 sample elements, and (e,f) PRCCs for ESTH230 and ESTH230C.
### Stepwise Rank Regression Analyses

#### Radioactivity Release Rates

**ESTH230:** Release rates (ESTH230, g/yr) and cumulative (ESTH230C, g) for the movement of dissolved 230Th from the EBS to the UZ resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository obtained with version 5.005 of the TSPA-LA Model.

- **(a)** Stepwise rank regression analyses and selected scatterplots for time-dependent release rates (ESTH230, g/yr) and cumulative (i.e., integrated) releases (ESTH230C, g) for the movement of dissolved 230Th from the EBS to the UZ resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository obtained with version 5.005 of the TSPA-LA Model: (a,b) regressions for ESTH230 and ESTH230C at 50,000, 200,000, and 500,000 years, and (c-h) scatterplots for ESTH230 and ESTH230C at 200,000 years.

#### Table

<table>
<thead>
<tr>
<th>Step</th>
<th>Variable</th>
<th>R²</th>
<th>SRRC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>INFIL</td>
<td>0.24</td>
<td>0.43</td>
</tr>
<tr>
<td>2</td>
<td>COLGW</td>
<td>0.42</td>
<td>0.43</td>
</tr>
<tr>
<td>3</td>
<td>KDSHSMEC</td>
<td>0.51</td>
<td>0.27</td>
</tr>
<tr>
<td>4</td>
<td>PHCSS</td>
<td>0.55</td>
<td>0.24</td>
</tr>
<tr>
<td>5</td>
<td>EP1LOWTH</td>
<td>0.59</td>
<td>0.22</td>
</tr>
<tr>
<td>6</td>
<td>UZKDTHTD</td>
<td>0.62</td>
<td>0.20</td>
</tr>
<tr>
<td>7</td>
<td>CORRATSS</td>
<td>0.66</td>
<td>0.17</td>
</tr>
<tr>
<td>8</td>
<td>GOESITED</td>
<td>0.68</td>
<td>0.13</td>
</tr>
<tr>
<td>9</td>
<td>EP1LOWOU</td>
<td>0.69</td>
<td>0.12</td>
</tr>
<tr>
<td>10</td>
<td>HLWMASS</td>
<td>0.70</td>
<td>0.10</td>
</tr>
<tr>
<td>11</td>
<td>RUBMAXL</td>
<td>0.65</td>
<td>0.09</td>
</tr>
</tbody>
</table>

#### Table (continued)

<table>
<thead>
<tr>
<th>Step</th>
<th>Variable</th>
<th>R²</th>
<th>SRRC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>INFIL</td>
<td>0.24</td>
<td>0.43</td>
</tr>
<tr>
<td>2</td>
<td>COLGW</td>
<td>0.43</td>
<td>0.45</td>
</tr>
<tr>
<td>3</td>
<td>KDSHSMEC</td>
<td>0.51</td>
<td>0.27</td>
</tr>
<tr>
<td>4</td>
<td>PHCSS</td>
<td>0.56</td>
<td>0.24</td>
</tr>
<tr>
<td>5</td>
<td>EP1LOWTH</td>
<td>0.60</td>
<td>0.22</td>
</tr>
<tr>
<td>6</td>
<td>UZKDTHTD</td>
<td>0.63</td>
<td>0.18</td>
</tr>
<tr>
<td>7</td>
<td>CORRATSS</td>
<td>0.66</td>
<td>0.13</td>
</tr>
<tr>
<td>8</td>
<td>GOESITED</td>
<td>0.69</td>
<td>0.12</td>
</tr>
<tr>
<td>9</td>
<td>EP1LOWOU</td>
<td>0.70</td>
<td>0.10</td>
</tr>
<tr>
<td>10</td>
<td>HLWMASS</td>
<td>0.71</td>
<td>0.10</td>
</tr>
<tr>
<td>11</td>
<td>RUBMAXL</td>
<td>0.72</td>
<td>-0.09</td>
</tr>
</tbody>
</table>

---

**Source:** Output DTNs: MO0801TSPAPRSA.000 [DIRS 184620]; and MO0710PLOTSFIG.000 [DIRS 185207].

**Figure K6.3.2-8[a].** Stepwise rank regression analyses and selected scatterplots for time-dependent release rates (ESTH230, g/yr) and cumulative (i.e., integrated) releases (ESTH230C, g) for the movement of dissolved 230Th from the EBS to the UZ resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository obtained with version 5.005 of the TSPA-LA Model: (a,b) regressions for ESTH230 and ESTH230C at 50,000, 200,000, and 500,000 years, and (c-h) scatterplots for ESTH230 and ESTH230C at 200,000 years.
Figure K6.3.2-8[a]. Stepwise rank regression analyses and selected scatterplots for time-dependent release rates (ESTH230, g/yr) and cumulative (i.e., integrated) releases (ESTH230C, g) for the movement of dissolved $^{230}$Th from the EBS to the UZ resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository obtained with version 5.005 of the TSPA-LA Model: (a,b) regressions for ESTH230 and ESTH230C at 50,000, 200,000, and 500,000 years, and (c-h) scatterplots for ESTH230 and ESTH230C at 200,000 years (continued)

Source: Output DTNs: MO0801TSPAPRSA.000 [DIRS 184620]; and MO0710PLOTSFIG.000 [DIRS 185207].

NOTE: In (c,f), the box extends from 0.25 to 0.75 quantile; lower and upper bar and whisker extend to 0.1 and 0.9 quantile, respectively; dots represent values outside 0.1 to 0.9 quantile range; median indicated by light horizontal line.
Figure K6.3.2-9[a] Time-dependent release rates ($ESRA226$, g/yr) and cumulative (i.e., integrated) releases ($ESRA226C$, g) over 1,000,000 years for the movement of dissolved $^{226}$Ra from the EBS to the UZ resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository obtained with version 5.005 of the TSPA-LA Model: (a,b) $ESRA226$ and $ESRA226C$ for all (i.e., 300) sample elements, (c,d) $ESRA226$ and $ESRA226C$ for first 50 sample elements, and (e,f) PRCCs for $ESRA226$ and $ESRA226C$.
Stepwise rank regression analyses and selected scatterplots for time-dependent release rates (ESRA226, g/yr) and cumulative (i.e., integrated) releases (ESRA226C, g) for the movement of dissolved 226Ra from the EBS to the UZ resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository obtained with version 5.005 of the TSPA-LA Model: (a,b) regressions for ESRA226 and ESRA226C at 50,000, 200,000, and 500,000 years, and (c-h) scatterplots for ESRA226 and ESRA226C at 50,000 years.

Source: Output DTNs: MO0801TSPAPRSA.000 [DIRS 184620]; and MO0710PLOTSFIG.000 [DIRS 185207].
Figure K6.3.2-10[a]. Stepwise rank regression analyses and selected scatterplots for time-dependent release rates (ESRA226, g/yr) and cumulative (i.e., integrated) releases (ESRA226C, g) for the movement of dissolved 226Ra from the EBS to the UZ resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository obtained with version 5.005 of the TSPA-LA Model: (a,b) regressions for ESRA226 and ESRA226C at 50,000, 200,000, and 500,000 years, and (c-h) scatterplots for ESRA226 and ESRA226C at 50,000 years (continued)
Figure K6.4.2-1[a]. Time-dependent release rates ($UZU234$, g/yr) and cumulative (i.e., integrated) releases ($UZU234C$, g) over 1,000,000 years for the movement of dissolved $^{234}$U from the UZ to the SZ resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository obtained with version 5.005 of the TSPA-LA Model: (a,b) $UZU234$ and $UZU234C$ for all (i.e., 300) sample elements, (c,d) $UZU234$ and $UZU234C$ for first 50 sample elements, and (e,f) PRCCs for $UZU234$ and $UZU234C$. 

Source: Output DTNs: MO0801TSPAPRSA.000 [DIRS 184620]; and MO0710PLOTSFIG.000 [DIRS 185207].
Figure K6.4.2-2[a]. Stepwise rank regression analyses and selected scatterplots for time-dependent release rates (UZU234, g/yr) and cumulative (i.e., integrated) releases (UZU234C, g) for the movement of dissolved 234U from the UZ to the SZ resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository obtained with version 5.005 of the TSPA-LA Model: (a,b) regressions for UZU234 and UZU234C at 50,000, 200,000, and 500,000 years, and (c-h) scatterplots for UZU234 and UZU234C at 500,000 years.
Figure K6.4.2-2[a]. Stepwise rank regression analyses and selected scatterplots for time-dependent release rates ($UZU234$, g/yr) and cumulative (i.e., integrated) releases ($UZU234C$, g) for the movement of dissolved $^{234}$U from the UZ to the SZ resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository obtained with version 5.005 of the TSPA-LA Model: (a,b) regressions for $UZU234$ and $UZU234C$ at 50,000, 200,000, and 500,000 years, and (c-h) scatterplots for $UZU234$ and $UZU234C$ at 500,000 years (continued).
Figure K.6.4.2-3[a]. Comparison of cumulative releases of dissolved $^{234}$U into the UZ ($ESU234C$, g) and out of the UZ ($UZU234C$, g) obtained with version 5.005 of the TSPA-LA Model at (a) 50,000, (b) 100,000, (c) 200,000, and (d) 600,000 years for an igneous intrusive event at 250 years that destroys all WPs in the repository.
Figure K6.4.2-4[a]. Time-dependent release rates ($UZTH230$, g/yr) and cumulative (i.e., integrated) releases ($UZTH230C$, g) over 1,000,000 years for the movement of dissolved $^{230}$Th from the UZ to the SZ resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository obtained with version 5.005 of the TSPA-LA Model: (a,b) $UZTH230$ and $UZTH230C$ for all (i.e., 300) sample elements, (c,d) $UZTH230$ and $UZTH230C$ for first 50 sample elements, and (e,f) PRCCs for $UZTH230$ and $UZTH230C$.
Figure K6.4.2-5[a].  Stepwise rank regression analyses and selected scatterplots for time-dependent release rates (UZTH230, g/yr) and cumulative (i.e., integrated) releases (UZTH230C, g) for the movement of dissolved $^{230}$Th from the UZ to the SZ resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository obtained with version 5.005 of the TSPA-LA Model: (a,b) regressions for UZTH230 and UZTH230C at 50,000, 200,000, and 500,000 years, and (c-h) scatterplots for UZTH230 and UZTH230C at 200,000 years.
Figure K6.4.2-5[a]. Stepwise rank regression analyses and selected scatterplots for time-dependent release rates (UZTH230, g/yr) and cumulative (i.e., integrated) releases (UZTH230C, g) for the movement of dissolved $^{230}$Th from the UZ to the SZ resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository obtained with version 5.005 of the TSPA-LA Model: (a,b) regressions for UZTH230 and UZTH230C at 50,000, 200,000, and 500,000 years, and (c-h) scatterplots for UZTH230 and UZTH230C at 200,000 years (continued).
Figure K.6.4.2-6[a]. Comparison of cumulative releases of dissolved $^{230}$Th into the UZ (ESTH230C, g) and out of the UZ (UZTH230C, g) obtained with version 5.005 of the TSPA-LA Model at (a) 50,000, (b) 100,000, (c) 200,000, and (d) 600,000 years for an igneous intrusive event at 250 years that destroys all WPs in the repository.

Source: Output DTNs: MO0801TSPAPRSA.000 [DIRS 184620]; and MO0710PLOTSFIG.000 [DIRS 185207].

MDL-WIS-PA-000005 REV 00 AD 01   FK-27[a]   March 2008
Time-dependent release rates ($UZRA226$, g/yr) and cumulative (i.e., integrated) releases ($UZRA226C$, g) over 1,000,000 years for the movement of dissolved $^{226}$Ra from the UZ to the SZ resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository obtained with version 5.005 of the TSPA-LA Model: (a,b) $UZRA226$ and $UZRA226C$ for all (i.e., 300) sample elements, (c,d) $UZRA226$ and $UZRA226C$ for first 50 sample elements, and (e,f) PRCCs for $UZRA226$ and $UZRA226C$.
Stepwise rank regression analyses and selected scatterplots for time-dependent release rates (UZRA226, g/yr) and cumulative (i.e., integrated) releases (UZRA226C, g) for the movement of dissolved $^{226}$Ra from the UZ to the SZ resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository obtained with version 5.005 of the TSPA-LA Model: (a,b) regressions for UZRA226 and UZRA226C at 50,000, 200,000, and 500,000 years, and (c-h) scatterplots for UZRA226 and UZRA226C at 50,000 years.

### Total System Performance Assessment Model/Analysis for the License Application

#### Source: Output DTNs: MO0801TSPAPRSA.000 [DIRS 184620]; and MO0710PLOTSFIG.000 [DIRS 185207].

#### Figure K6.4.2-8[a].

<table>
<thead>
<tr>
<th>Step&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Variable&lt;sup&gt;b&lt;/sup&gt;</th>
<th>$R^2$</th>
<th>SRRC&lt;sup&gt;d&lt;/sup&gt;</th>
<th>Variable</th>
<th>$R^2$</th>
<th>SRRC</th>
<th>Variable</th>
<th>$R^2$</th>
<th>SRRC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>UZKDCSDT</td>
<td>0.41</td>
<td>−0.64</td>
<td>INFIL</td>
<td>0.27</td>
<td>0.52</td>
<td>UZKDCSDT</td>
<td>0.24</td>
<td>−0.47</td>
</tr>
<tr>
<td>2</td>
<td>INFIL</td>
<td>0.72</td>
<td>0.54</td>
<td>UZKDCSDT</td>
<td>0.52</td>
<td>−0.48</td>
<td>UZFAG8</td>
<td>0.41</td>
<td>0.42</td>
</tr>
<tr>
<td>3</td>
<td>UZFAG8</td>
<td>0.76</td>
<td>0.20</td>
<td>UZFAG8</td>
<td>0.67</td>
<td>0.38</td>
<td>INFIL</td>
<td>0.56</td>
<td>0.39</td>
</tr>
<tr>
<td>4</td>
<td>CSNFMASS</td>
<td>0.78</td>
<td>0.15</td>
<td>UZTORRG3</td>
<td>0.77</td>
<td>−0.33</td>
<td>UZTORRG3</td>
<td>0.64</td>
<td>−0.32</td>
</tr>
<tr>
<td>5</td>
<td>UZTORRG3</td>
<td>0.80</td>
<td>−0.14</td>
<td>CSNFMASS</td>
<td>0.78</td>
<td>0.13</td>
<td>EP1LOWOU</td>
<td>0.68</td>
<td>−0.22</td>
</tr>
<tr>
<td>6</td>
<td>KDNPSMEC</td>
<td>0.80</td>
<td>0.08</td>
<td>COLGW</td>
<td>0.79</td>
<td>0.09</td>
<td>CSNFMASS</td>
<td>0.70</td>
<td>0.13</td>
</tr>
<tr>
<td>7</td>
<td>KDAMSME C</td>
<td>0.81</td>
<td>−0.08</td>
<td>UZGAM</td>
<td>0.80</td>
<td>0.07</td>
<td>UZKDTDIS</td>
<td>0.71</td>
<td>0.11</td>
</tr>
<tr>
<td>8</td>
<td>KDNPCOL</td>
<td>0.81</td>
<td>0.07</td>
<td>UZKDTDHDT</td>
<td>0.80</td>
<td>0.08</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td>EP1LOWOU</td>
<td>0.81</td>
<td>−0.07</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**a**: Steps in stepwise rank regression analysis  
**b**: Variables listed in order of selection in stepwise regression  
**c**: Cumulative $R^2$ value with entry of each variable into regression model  
**d**: Standardized rank regression coefficients (SRRCs) in final regression model
Figure K6.4.2-8[a]. Stepwise rank regression analyses and selected scatterplots for time-dependent release rates (UZRA226, g/yr) and cumulative (i.e., integrated) releases (UZRA226C, g) for the movement of dissolved $^{226}$Ra from the UZ to the SZ resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository obtained with version 5.005 of the TSPA-LA Model: (a,b) regressions for UZRA226 and UZRA226C at 50,000, 200,000, and 500,000 years, and (c-h) scatterplots for UZRA226 and UZRA226C at 50,000 years (continued)

Source: Output DTNs: MO0801TSPAPRSA.000 [DIRS 184620]; and MO0710PLOTSFIG.000 [DIRS 185207].

NOTE: In (d,g), the box extends from 0.25 to 0.75 quantile; lower and upper bar and whisker extend to 0.1 and 0.9 quantile, respectively; dots represent values outside 0.1 to 0.9 quantile range; median indicated by light horizontal line.
Figure K.6.4.2-9[a]. Comparison of cumulative releases of dissolved $^{226}$Ra into the UZ ($UZRA226C$, g) and out of the UZ ($UZRA226C$, g) obtained with version 5.005 of the TSPA-LA Model at (a) 50,000, (b) 100,000, (c) 200,000, and (d) 600,000 years for an igneous intrusive event at 250 years that destroys all WPs in the repository.
Figure K6.5.2-5[a]. Time-dependent release rates (SZU234, g/yr) and cumulative (i.e., integrated) releases (SZU234C, g) over 1,000,000 years for the movement of dissolved $^{234}$U across a subsurface plane at the location of the RMEI resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository obtained with version 5.005 of the TSPA-LA Model: (a,b) SZU234 and SZU234C for all (i.e., 300) sample elements, (c,d) SZU234 and SZU234C for first 50 sample elements, and (e,f) PRCCs for SZU234 and SZU234C.
Total System Performance Assessment Model/Analysis for the License Application

### Source:
Output DTNs: MO0801TSPAPRSA.000 [DIRS 184620]; and MO0710PLOTSFIG.000 [DIRS 185207].

Figure K6.5.2-6[a]. Stepwise rank regression analyses and selected scatterplots for time-dependent release rates (SZU234, g/yr) and cumulative (i.e., integrated) releases (SZU234C, g) for the movement of dissolved $^{234}$U across a subsurface plane at the location of the RMEI resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository obtained with version 5.005 of the TSPA-LA Model: (a,b) regressions for SZU234 and SZU234C at 50,000, 200,000, and 500,000 years, and (c-h) scatterplots for SZU234 and SZU234C at 500,000 years.

<table>
<thead>
<tr>
<th>(a)</th>
<th>SZU234: 50,000 Years</th>
<th>SZU234: 200,000 Years</th>
<th>SZU234: 500,000 Years</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Step</strong></td>
<td><strong>Variable</strong></td>
<td><strong>R$^2$</strong></td>
<td><strong>SRRC</strong></td>
</tr>
<tr>
<td>1</td>
<td>EP1LOWOU</td>
<td>0.30</td>
<td>0.53</td>
</tr>
<tr>
<td>2</td>
<td>INFIL</td>
<td>0.42</td>
<td>0.36</td>
</tr>
<tr>
<td>3</td>
<td>SZGWSPDMD</td>
<td>0.49</td>
<td>0.28</td>
</tr>
<tr>
<td>4</td>
<td>GOESITED</td>
<td>0.55</td>
<td>-0.22</td>
</tr>
<tr>
<td>5</td>
<td>CORRATSS</td>
<td>0.59</td>
<td>-0.22</td>
</tr>
<tr>
<td>6</td>
<td>PHCSS</td>
<td>0.62</td>
<td>0.17</td>
</tr>
<tr>
<td>7</td>
<td>IS2MCOS</td>
<td>0.64</td>
<td>0.15</td>
</tr>
<tr>
<td>8</td>
<td>CSNFMASS</td>
<td>0.66</td>
<td>0.14</td>
</tr>
<tr>
<td>9</td>
<td>SZDIFCVO</td>
<td>0.68</td>
<td>-0.15</td>
</tr>
<tr>
<td>10</td>
<td>SZFISPVO</td>
<td>0.70</td>
<td>0.13</td>
</tr>
<tr>
<td>11</td>
<td>KDPUSMEC</td>
<td>0.71</td>
<td>0.12</td>
</tr>
<tr>
<td>12</td>
<td>GOERELAB</td>
<td>0.72</td>
<td>0.11</td>
</tr>
<tr>
<td>13</td>
<td>HFOSA</td>
<td>0.73</td>
<td>-0.12</td>
</tr>
<tr>
<td>14</td>
<td>CSWF44AC</td>
<td>0.73</td>
<td>-0.10</td>
</tr>
<tr>
<td>15</td>
<td>DELPPCO2</td>
<td>0.74</td>
<td>0.09</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>(b)</th>
<th>SZU234C: 50,000 Years</th>
<th>SZU234C: 200,000 Years</th>
<th>SZU234C: 500,000 Years</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Step</strong></td>
<td><strong>Variable</strong></td>
<td><strong>R$^2$</strong></td>
<td><strong>SRRC</strong></td>
</tr>
<tr>
<td>1</td>
<td>EP1LOWOU</td>
<td>0.26</td>
<td>0.51</td>
</tr>
<tr>
<td>2</td>
<td>INFIL</td>
<td>0.38</td>
<td>0.35</td>
</tr>
<tr>
<td>3</td>
<td>SZGWSPDMD</td>
<td>0.49</td>
<td>0.35</td>
</tr>
<tr>
<td>4</td>
<td>GOESITED</td>
<td>0.55</td>
<td>-0.20</td>
</tr>
<tr>
<td>5</td>
<td>SZDIFCVO</td>
<td>0.58</td>
<td>-0.18</td>
</tr>
<tr>
<td>6</td>
<td>SZFISPVO</td>
<td>0.61</td>
<td>0.17</td>
</tr>
<tr>
<td>7</td>
<td>CORRATSS</td>
<td>0.64</td>
<td>-0.19</td>
</tr>
<tr>
<td>8</td>
<td>PHCSS</td>
<td>0.66</td>
<td>0.16</td>
</tr>
<tr>
<td>9</td>
<td>IS2MCOS</td>
<td>0.68</td>
<td>0.17</td>
</tr>
<tr>
<td>10</td>
<td>CSNFMASS</td>
<td>0.70</td>
<td>0.12</td>
</tr>
<tr>
<td>11</td>
<td>KDPUSMEC</td>
<td>0.71</td>
<td>0.11</td>
</tr>
<tr>
<td>12</td>
<td>DELPPCO2</td>
<td>0.72</td>
<td>0.11</td>
</tr>
<tr>
<td>13</td>
<td>HFOSA</td>
<td>0.72</td>
<td>-0.10</td>
</tr>
<tr>
<td>14</td>
<td>DSCRACKA</td>
<td>0.73</td>
<td>-0.10</td>
</tr>
<tr>
<td>15</td>
<td>CSWF44AC</td>
<td>0.74</td>
<td>-0.09</td>
</tr>
<tr>
<td>16</td>
<td>GOERELAB</td>
<td>0.75</td>
<td>0.09</td>
</tr>
</tbody>
</table>

**Notes:**
- a: Steps in stepwise rank regression analysis
- b: Variables listed in order of selection in stepwise regression
- c: Cumulative $R^2$ value with entry of each variable into regression model
- d: Standardized rank regression coefficients (SRRCs) in final regression model
Stepwise rank regression analyses and selected scatterplots for time-dependent release rates (SZU234, g/yr) and cumulative (i.e., integrated) releases (SZU234C, g) for the movement of dissolved $^{234}$U across a subsurface plane at the location of the RMEI resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository obtained with version 5.005 of the TSPA-LA Model:

(a,b) regressions for SZU234 and SZU234C at 50,000, 200,000, and 500,000 years, and (c-h) scatterplots for SZU234 and SZU234C at 500,000 years (continued)
Figure K.6.5.2-7[a]. Comparison of cumulative releases of dissolved $^{234}$U into the SZ (UZU234C, g) and across a subsurface plane at the location of the RMEI (SZU234C, g) obtained with version 5.005 of the TSPA-LA Model at (a) 50,000, (b) 100,000, (c) 200,000, and (d) 600,000 years for an igneous intrusive event at 250 years that destroys all WPs in the repository.

Source: Output DTNs: MO0801TSPAPRSA.000 [DIRS 184620]; and MO0710PLOTSFIG.000 [DIRS 185207].
Figure K6.5.2-8[a]. Time-dependent release rates ($SZTH230$, g/yr) and cumulative (i.e., integrated) releases ($SZTH230C$, g) over 1,000,000 years for the movement of dissolved $^{230}$Th across a subsurface plane at the location of the RMEI resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository obtained with version 5.005 of the TSPA-LA Model: (a,b) $SZTH230$ and $SZTH230C$ for all (i.e., 300) sample elements, (c,d) $SZTH230$ and $SZTH230C$ for first 50 sample elements, and (e,f) PRCCs for $SZTH230$ and $SZTH230C$.
Figure K6.5.2-9[a]. Stepwise rank regression analyses and selected scatterplots for time-dependent release rates (SZTH230, g/yr) and cumulative (i.e., integrated) releases (SZTH230C, g) for the movement of dissolved $^{230}$Th across a subsurface plane at the location of the RMEI resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository obtained with version 5.005 of the TSPA-LA Model: (a,b) regressions for SZTH230 and SZTH230C at 50,000, 200,000, and 500,000 years, and (c-h) scatterplots for SZTH230 and SZTH230C at 500,000 years.

Source: Output DTNs: MO0801TSPAPRSA.000 [DIRS 184620]; and MO0710PLOTSFIG.000 [DIRS 185207].
Figure K6.5.2-9[a]. Stepwise rank regression analyses and selected scatterplots for time-dependent release rates (SZTH230, g/yr) and cumulative (i.e., integrated) releases (SZTH230C, g) for the movement of dissolved $^{230}$Th across a subsurface plane at the location of the RMEI resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository obtained with version 5.005 of the TSPA-LA Model: (a,b) regressions for SZTH230 and SZTH230C at 50,000, 200,000, and 500,000 years, and (c-h) scatterplots for SZTH230 and SZTH230C at 500,000 years (continued)
Figure K.6.5.2-10[a]. Comparison of cumulative releases of dissolved $^{230}$Th into the SZ (UZTH230C, g) and across a subsurface plane at the location of the RMEI (SZTH230C, g) obtained with version 5.005 of the TSPA-LA Model at (a) 50,000, (b) 100,000, (c) 200,000, and (d) 600,000 years for an igneous intrusive event at 250 years that destroys all WPs in the repository.

Source: Output DTNs: MO0801TSPAPRSA.000 [DIRS 184620]; and MO0710PLOTSFIG.000 [DIRS 185207].
Figure K6.5.2-11[a]. Time-dependent release rates (SZRA226, g/yr) and cumulative (i.e., integrated) releases (SZRA226C, g) over 1,000,000 years for the movement of dissolved $^{226}$Ra across a subsurface plane at the location of the RMEI resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository obtained with version 5.005 of the TSPA-LA Model: (a,b) SZRA226 and SZRA226C for all (i.e., 300) sample elements, (c,d) SZRA226 and SZRA226C for first 50 sample elements, and (e,f) PRCCs for SZRA226 and SZRA226C.

Source: Output DTNs: MO0801TSPAPRSA.000 [DIRS 184620]; and MO0710PLOTSFIG.000 [DIRS 185207].
### Stepwise rank regression analyses for time-dependent release rates and cumulative releases

<table>
<thead>
<tr>
<th>Step</th>
<th>Variable</th>
<th>R²</th>
<th>SRC</th>
<th>Variable</th>
<th>R²</th>
<th>SRC</th>
<th>Variable</th>
<th>R²</th>
<th>SRC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SZGWSPD</td>
<td>0.22</td>
<td>0.48</td>
<td>EP1LOWO</td>
<td>0.19</td>
<td>0.43</td>
<td>EP1LOWO</td>
<td>0.21</td>
<td>0.45</td>
</tr>
<tr>
<td>2</td>
<td>EP1LOWO</td>
<td>0.40</td>
<td>0.43</td>
<td>SZGWSPD</td>
<td>0.28</td>
<td>0.34</td>
<td>SZCONC</td>
<td>0.37</td>
<td>0.27</td>
</tr>
<tr>
<td>3</td>
<td>INFIL</td>
<td>0.48</td>
<td>0.32</td>
<td>INFIL</td>
<td>0.41</td>
<td>0.26</td>
<td>SZGWSPD</td>
<td>0.45</td>
<td>0.27</td>
</tr>
<tr>
<td>4</td>
<td>GOESITED</td>
<td>0.52</td>
<td>0.20</td>
<td>GOESITED</td>
<td>0.47</td>
<td>0.26</td>
<td>INFIL</td>
<td>0.49</td>
<td>0.22</td>
</tr>
<tr>
<td>5</td>
<td>SZKDRRA</td>
<td>0.56</td>
<td>0.21</td>
<td>SZCONC</td>
<td>0.52</td>
<td>0.20</td>
<td>SZKDMCO</td>
<td>0.53</td>
<td>0.20</td>
</tr>
<tr>
<td>6</td>
<td>CORRATSS</td>
<td>0.58</td>
<td>0.15</td>
<td>HFOS</td>
<td>0.55</td>
<td>0.16</td>
<td>GOESITED</td>
<td>0.56</td>
<td>0.21</td>
</tr>
<tr>
<td>7</td>
<td>PHCSS</td>
<td>0.60</td>
<td>0.13</td>
<td>SZKDMCO</td>
<td>0.57</td>
<td>0.13</td>
<td>PHCSS</td>
<td>0.59</td>
<td>0.14</td>
</tr>
<tr>
<td>8</td>
<td>IS2MCOS</td>
<td>0.61</td>
<td>0.13</td>
<td>PHCSS</td>
<td>0.59</td>
<td>0.15</td>
<td>HFOS</td>
<td>0.61</td>
<td>0.15</td>
</tr>
<tr>
<td>9</td>
<td>CNSMMASS</td>
<td>0.63</td>
<td>0.12</td>
<td>CORRATSS</td>
<td>0.61</td>
<td>0.15</td>
<td>SZKDMO</td>
<td>0.62</td>
<td>0.13</td>
</tr>
<tr>
<td>10</td>
<td>KPDUSMEC</td>
<td>0.65</td>
<td>0.16</td>
<td>KPDUSMEC</td>
<td>0.63</td>
<td>0.12</td>
<td>SZKDRRA</td>
<td>0.63</td>
<td>0.28</td>
</tr>
<tr>
<td>11</td>
<td>UZFA4G</td>
<td>0.66</td>
<td>0.10</td>
<td>UZFA4G</td>
<td>0.64</td>
<td>0.12</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>THERMCON</td>
<td>0.67</td>
<td>0.11</td>
<td>HLWDRALK</td>
<td>0.65</td>
<td>0.11</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>HFOS</td>
<td>0.67</td>
<td>0.09</td>
<td>SZKDMO</td>
<td>0.66</td>
<td>0.09</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>SZRAHAO</td>
<td>0.68</td>
<td>0.11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>DSCRACKA</td>
<td>0.69</td>
<td>0.09</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>SZDIFCVO</td>
<td>0.70</td>
<td>0.09</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **a:** Steps in stepwise rank regression analysis
- **b:** Variables listed in order of selection in stepwise regression
- **c:** Cumulative $R^2$ value with entry of each variable into regression model
- **d:** Standardized rank regression coefficients (SRCRs) in final regression model

Source: Output DTNs: MO0801TSPAPRSA.000 [DIRS 184620]; and MO0710PLOTSFIG.000 [DIRS 185207].

Figure K6.5.2-12[a]. Stepwise rank regression analyses and selected scatterplots for time-dependent release rates (SZRA226, g/yr) and cumulative (i.e., integrated) releases (SZRA226C, g) for the movement of dissolved $^{226}$Ra across a subsurface plane at the location of the RMEI resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository obtained with version 5.005 of the TSPA-LA Model: (a,b) regressions for SZRA226 and SZRA226C at 50,000, 200,000, and 500,000 years, and (c-h) scatterplots for SZRA226 and SZRA226C at 50,000 years.
Stepwise rank regression analyses and selected scatterplots for time-dependent release rates (SZRA226, g/yr) and cumulative (i.e., integrated) releases (SZRA226C, g) for the movement of dissolved 226Ra across a subsurface plane at the location of the RMEI resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository obtained with version 5.005 of the TSPA-LA Model: (a,b) regressions for SZRA226 and SZRA226C at 50,000, 200,000, and 500,000 years, and (c-h) scatterplots for SZRA226 and SZRA226C at 50,000 years.

Source: Output DTNs: MO0801TSPAPRSA.000 [DIRS 184620]; and MO0710PLOTSFIG.000 [DIRS 185207].

NOTE: In (e,h), the box extends from 0.25 to 0.75 quantile; lower and upper bar and whisker extend to 0.1 and 0.9 quantile, respectively; dots represent values outside 0.1 to 0.9 quantile range; median indicated by light horizontal line.

Figure K6.5.2-12[a].
Comparison of cumulative releases of dissolved $^{226}$Ra into the SZ (UZRA226C, g) and across a subsurface plane at the location of the RMEI (SZRA226C, g) obtained with version 5.005 of the TSPA-LA Model at (a) 50,000, (b) 100,000, (c) 200,000, and (d) 600,000 years for an igneous intrusive event at 250 years that destroys all WPs in the repository.
Figure K.6.6.2-5[a]. Time-dependent dose to the RMEI \((DOU234, \text{ mrem/yr})\) over 1,000,000 years for the movement of dissolved \(^{234}\text{U}\) across a subsurface plane at the location of the RMEI resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository obtained with version 5.005 of the TSPA-LA Model: (a) \(DOU234\) for all (i.e., 300) sample elements, (b) \(DOU234\) for first 50 sample elements, and (c) PRCCs for \(DOU234\)
Figure K.6.6.2-6[a]: Stepwise rank regression analyses and selected scatterplots for time-dependent dose to the RMEI (DOU234, mrem/yr) for the movement of dissolved $^{234}$U across a subsurface plane at the location of the RMEI ($SZU234$, g/yr) resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository obtained with version 5.005 of the TSPA-LA Model: (a) regressions for DOU234 at 50,000, 200,000, and 500,000 years, (b,c,d) scatterplots for DOU234 at 500,000 years, and (e) scatterplot comparing $SZU234$ and DOU234 at 500,000 years.
Time-dependent dose to the RMEI ($DOTH230$, mrem/yr) over 1,000,000 years for the movement of dissolved $^{230}$Th across a subsurface plane at the location of the RMEI resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository obtained with version 5.005 of the TSPA-LA Model: 

(a) $DOTH230$ for all (i.e., 300) sample elements, 
(b) $DOTH230$ for first 50 sample elements, and 
(c) PRCCs for $DOTH230$
Figure K.6.6.2-8[a]. Stepwise rank regression analyses and selected scatterplots for time-dependent dose to the RMEI (DOTh230, mrem/yr) for the movement of dissolved $^{230}$Th across a subsurface plane at the location of the RMEI (SZTH230, g/yr) resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository obtained with version 5.005 of the TSPA-LA Model: (a) regressions for DOTh230 at 50,000, 200,000, and 500,000 years, (b,c,d) scatterplots for DOTh230 at 500,000 years, and (e) scatterplot comparing SZTH230 and DOTh230 at 500,000 years.

Source: Output DTNs: MO0801TSPAPRSA.000 [DIRS 184620]; and MO0710PLOTSFIG.000 [DIRS 185207].
Figure K.6.6.2-9[a]. Time-dependent dose to the RMEI (DORA226, mrem/yr) over 1,000,000 years for the movement of dissolved $^{226}$Ra across a subsurface plane at the location of the RMEI resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository obtained with version 5.005 of the TSPA-LA Model: (a) DORA226 for all (i.e., 300) sample elements, (b) DORA226 for first 50 sample elements, and (c) PRCCs for DORA226.
Total System Performance Assessment Model/Analysis for the License Application

(a) DORA226: 50,000 Years

<table>
<thead>
<tr>
<th>Step</th>
<th>Variable</th>
<th>$r^2$</th>
<th>SRC</th>
<th>Step</th>
<th>Variable</th>
<th>$r^2$</th>
<th>SRC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SZGWSPDM</td>
<td>0.21</td>
<td>0.50</td>
<td>EPILOWOU</td>
<td>0.19</td>
<td>0.43</td>
<td>EPILOWOU</td>
</tr>
<tr>
<td>2</td>
<td>EPILLOWOU</td>
<td>0.39</td>
<td>0.43</td>
<td>SZKDCSAL</td>
<td>0.28</td>
<td>-0.24</td>
<td>SZKDCSAL</td>
</tr>
<tr>
<td>3</td>
<td>INFIL</td>
<td>0.47</td>
<td>0.32</td>
<td>SZGWSPDM</td>
<td>0.34</td>
<td>0.32</td>
<td>SZCONCOL</td>
</tr>
<tr>
<td>4</td>
<td>GOESITED</td>
<td>0.51</td>
<td>-0.19</td>
<td>INFIL</td>
<td>0.40</td>
<td>0.25</td>
<td>SZGWSPDM</td>
</tr>
<tr>
<td>5</td>
<td>SZKDRAL</td>
<td>0.55</td>
<td>-0.20</td>
<td>MICRA226</td>
<td>0.45</td>
<td>0.24</td>
<td>INFIL</td>
</tr>
<tr>
<td>6</td>
<td>MICRA226</td>
<td>0.58</td>
<td>0.17</td>
<td>GOESITED</td>
<td>0.51</td>
<td>-0.23</td>
<td>MICRA226</td>
</tr>
<tr>
<td>7</td>
<td>KDPUSMEC</td>
<td>0.60</td>
<td>0.16</td>
<td>SZCONCOL</td>
<td>0.55</td>
<td>0.20</td>
<td>SZKDAAMCO</td>
</tr>
<tr>
<td>8</td>
<td>UZFAGal</td>
<td>0.62</td>
<td>-0.11</td>
<td>HFOSA</td>
<td>0.58</td>
<td>-0.15</td>
<td>GOESITED</td>
</tr>
<tr>
<td>9</td>
<td>PHCSS</td>
<td>0.64</td>
<td>0.14</td>
<td>PHCSS</td>
<td>0.60</td>
<td>0.16</td>
<td>PHCSS</td>
</tr>
<tr>
<td>10</td>
<td>CORRATSS</td>
<td>0.65</td>
<td>-0.15</td>
<td>SZKDAAMCO</td>
<td>0.62</td>
<td>0.13</td>
<td>HFOSA</td>
</tr>
<tr>
<td>11</td>
<td>ISZMCOS</td>
<td>0.66</td>
<td>0.14</td>
<td>CORRATSS</td>
<td>0.64</td>
<td>-0.12</td>
<td>SZKDAJAL</td>
</tr>
<tr>
<td>12</td>
<td>CSNFMASS</td>
<td>0.68</td>
<td>0.11</td>
<td>KDPUSMEC</td>
<td>0.65</td>
<td>0.11</td>
<td>SZRAHADO</td>
</tr>
<tr>
<td>13</td>
<td>SZCONCOL</td>
<td>0.69</td>
<td>0.09</td>
<td>UZFAGal</td>
<td>0.66</td>
<td>-0.12</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>HFOSA</td>
<td>0.70</td>
<td>-0.09</td>
<td>HLVDRALK</td>
<td>0.67</td>
<td>0.11</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>THERMCN</td>
<td>0.70</td>
<td>0.09</td>
<td>SZKDAJAL</td>
<td>0.68</td>
<td>-0.10</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>SZDENAL</td>
<td>0.68</td>
<td>-0.59</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a. Steps in stepwise rank regression analysis
b. Variables listed in order of selection in stepwise regression
c. Cumulative $R^2$ value with entry of each variable into regression model
d. Standardized rank regression coefficients (SRCs) in final regression model

Source: Output DTNs: MO0801TSPAPRSA.000 [DIRS 184620]; and MO0710PLOTSFIG.000 [DIRS 185207].

NOTE: In (d), the box extends from 0.25 to 0.75 quantile; lower and upper bar and whisker extend to 0.1 and 0.9 quantile, respectively; dots represent values outside 0.1 to 0.9 quantile range; median indicated by light horizontal line.

Figure K.6.6.2-10[a]. Stepwise rank regression analyses and selected scatterplots for time-dependent dose to the RMEI (DORA226, mrem/yr) for the movement of dissolved $^{226}\text{Ra}$ across a subsurface plane at the location of the RMEI (SZRA226, g/yr) resulting from an igneous intrusive event at 250 years that destroys all WPs in the repository obtained with version 5.005 of the TSPA-LA Model: (a) regressions for DORA226 at 50,000, 200,000, and 500,000 years, (b,c,d) scatterplots for DORA226 at 50,000 years, and (e) scatterplot comparing SZRA226 and DORA226 at 50,000 years.
Figure K6.7.1-1[a]. Expected dose to RMEI (EXPDOSE, mrem/yr) over [0, 20,000 yr] for all radioactive species resulting from igneous intrusion obtained with version 5.005 of the TSPA-LA Model: (a) EXPDOSE for all (i.e., 300) sample elements, (b) EXPDOSE for first 50 sample elements, and (c) PRCCs for EXPDOSE.
Figure K6.7.1-2[a]. Stepwise rank regression analyses and selected scatterplots for expected dose to RMEI (EXPDOSE, mrem/yr) over [0, 20,000 yr] for all radioactive species resulting from igneous intrusion obtained with version 5.005 of the TSPA-LA Model: (a) regressions for EXPDOSE at 3,000, 5,000, and 10,000 years, and (b,c,d) scatterplots for EXPDOSE at 10,000 years.
Figure K.6.7.2-1[a]. Expected dose to RMEI (EXPDOSE, mrem/yr) over [0, 1,000,000 yr] for all radioactive species resulting from igneous intrusion obtained with version 5.005 of the TSPA-LA Model: (a) EXPDOSE for all (i.e., 300) sample elements, (b) EXPDOSE for first 50 sample elements, and (c) PRCCs for EXPDOSE.
Figure K.6.7.2-2[a]. Stepwise rank regression analyses and selected scatterplots for expected dose to RMEI (EXPDOSE, mrem/yr) over [0, 1,000,000 yr] for all radioactive species resulting from igneous intrusion obtained with version 5.005 of the TSPA-LA Model: (a) regressions for EXPDOSE at 50,000, 200,000, and 500,000 years, and (b,c,d) scatterplots for EXPDOSE at 500,000 years.

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0710PLOTSFIG.000 [DIRS 185207].

NOTE: In (d), the box extends from 0.25 to 0.75 quantile; lower and upper bar and whisker extend to 0.1 and 0.9 quantile, respectively; dots represent values outside 0.1 to 0.9 quantile range; median indicated by light horizontal line.

Stepwise rank regression analysis

a: Steps in stepwise rank regression analysis
b: Variables listed in order of selection in stepwise regression
c: Cumulative R² value with entry of each variable into regression model
d: Standardized rank regression coefficients (SRRCs) in final regression model

<table>
<thead>
<tr>
<th>Step</th>
<th>Variable</th>
<th>EXPDOSE: 50,000 Years</th>
<th>EXPDOSE: 200,000 Years</th>
<th>EXPDOSE: 500,000 Years</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Variable</td>
<td>R²</td>
<td>SRRC</td>
</tr>
<tr>
<td>1</td>
<td>IGRAFTE</td>
<td>0.53</td>
<td>0.72</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>SZGWSPD</td>
<td>0.69</td>
<td>0.36</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>EP1LOWPU</td>
<td>0.74</td>
<td>0.20</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>INIFL</td>
<td>0.77</td>
<td>0.16</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>EP1HPO2</td>
<td>0.78</td>
<td>0.11</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>MICPD23</td>
<td>0.79</td>
<td>0.11</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>CPUCOLWF</td>
<td>0.80</td>
<td>0.13</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>SFIRSPDO</td>
<td>0.81</td>
<td>0.11</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>SZCQLRCL</td>
<td>0.82</td>
<td>0.10</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>KDRASMEC</td>
<td>0.83</td>
<td>0.08</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>SDFCPLV</td>
<td>0.84</td>
<td>0.09</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>SZZCQLRCL</td>
<td>0.85</td>
<td>0.08</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>PHCSS</td>
<td>0.85</td>
<td>0.07</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>SZZKDOAMC</td>
<td>0.85</td>
<td>0.06</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>SCHOBOLT</td>
<td>0.86</td>
<td>0.07</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>MICPD23</td>
<td>0.86</td>
<td>0.11</td>
<td></td>
</tr>
</tbody>
</table>
Figure K7.7.1-1. Expected dose to RMEI ($\text{EXPDOSE}$, mrem/yr) over [0, 20,000 yr] for all radioactive species resulting from seismic ground motion obtained with version 5.005 of the TSPA-LA Model: (a) $\text{EXPDOSE}$ for all (i.e., 300) sample elements, (b) $\text{EXPDOSE}$ for first 50 sample elements, and (c) PRCCs for $\text{EXPDOSE}$.

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0710PLOTSFIG.000 [DIRS 185207].
Figure K7.7.1-2[a]. Stepwise rank regression analyses and selected scatterplots for expected dose to RMEI (EXPDOSE, mrem/yr) over [0, 20,000 yr] for all radioactive species resulting from seismic ground motion obtained with version 5.005 of the TSPA-LA Model: (a) regressions for EXPDOSE at 3,000, 5,000, and 10,000 years, and (b,c,d) scatterplots for EXPDOSE at 10,000 years.

Source: Output DTNs: MO0710ADTPAWO.000 [DIRS 183752]; and MO0710PLOTSFIG.000 [DIRS 185207].
Figure K7.7.2-1[a]. Expected dose to RMEI ($EXPDOSE$, mrem/yr) over [0, 1,000,000 yr] for all radioactive species resulting from seismic ground motion obtained with version 5.005 of the TSPA-LA Model: (a) $EXPDOSE$ for all (i.e., 300) sample elements, (b) $EXPDOSE$ for first 50 sample elements, and (c) PRCCs for $EXPDOSE$

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0710PLOTSFIG.000 [DIRS 185207].
Total System Performance Assessment Model/Analysis for the License Application

Figure K7.7.2-2[a]. Stepwise rank regression analyses and selected scatterplots for expected dose to RMEI ($\text{EXPDOSE}$, mrem/yr) over [0, 1,000,000 yr] for all radioactive species resulting from seismic ground motion obtained with version 5.005 of the TSPA-LA Model: (a) regressions for $\text{EXPDOSE}$ at 50,000, 200,000, and 500,000 years, and (b,c,d) scatterplots for $\text{EXPDOSE}$ at 500,000 years

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0710PLOTSFIG.000 [DIRS 185207].

### Table: Stepwise rank regression analyses and selected scatterplots for expected dose to RMEI ($\text{EXPDOSE}$, mrem/yr)

<table>
<thead>
<tr>
<th>Step</th>
<th>Variable</th>
<th>$R^2$</th>
<th>SRRC</th>
<th>Step</th>
<th>Variable</th>
<th>$R^2$</th>
<th>SRRC</th>
<th>Step</th>
<th>Variable</th>
<th>$R^2$</th>
<th>SRRC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SCCTHRP</td>
<td>0.71</td>
<td>-0.85</td>
<td>5</td>
<td>SCCTHRP</td>
<td>0.54</td>
<td>-0.72</td>
<td>1</td>
<td>WDGCA22</td>
<td>0.62</td>
<td>-0.77</td>
</tr>
<tr>
<td>2</td>
<td>MICTC99</td>
<td>0.72</td>
<td>0.09</td>
<td>6</td>
<td>WDGCA22</td>
<td>0.60</td>
<td>-0.14</td>
<td>2</td>
<td>WDSSGC29</td>
<td>0.58</td>
<td>-0.18</td>
</tr>
<tr>
<td>3</td>
<td>HLWDRACD</td>
<td>0.73</td>
<td>0.10</td>
<td>7</td>
<td>WDSSGC29</td>
<td>0.60</td>
<td>-0.14</td>
<td>3</td>
<td>WDGCA22</td>
<td>0.60</td>
<td>-0.14</td>
</tr>
<tr>
<td>4</td>
<td>DSNFMAS+</td>
<td>0.74</td>
<td>0.11</td>
<td>8</td>
<td>WDGCA22</td>
<td>0.60</td>
<td>-0.14</td>
<td>4</td>
<td>DSNFMAS+</td>
<td>0.74</td>
<td>0.11</td>
</tr>
<tr>
<td>5</td>
<td>SZLODISP</td>
<td>0.75</td>
<td>-0.10</td>
<td>5</td>
<td>DSNFMAS+</td>
<td>0.74</td>
<td>0.11</td>
<td>5</td>
<td>DSNFMAS+</td>
<td>0.74</td>
<td>0.11</td>
</tr>
<tr>
<td>6</td>
<td>SZKDEVO</td>
<td>0.76</td>
<td>-0.09</td>
<td>6</td>
<td>DSNFMAS+</td>
<td>0.74</td>
<td>0.11</td>
<td>6</td>
<td>DSNFMAS+</td>
<td>0.74</td>
<td>0.11</td>
</tr>
<tr>
<td>7</td>
<td>CPUPERCNS+</td>
<td>0.77</td>
<td>0.09</td>
<td>7</td>
<td>DSNFMAS+</td>
<td>0.74</td>
<td>0.11</td>
<td>7</td>
<td>DSNFMAS+</td>
<td>0.74</td>
<td>0.11</td>
</tr>
<tr>
<td>8</td>
<td>UZFAJ4</td>
<td>0.76</td>
<td>-0.08</td>
<td>8</td>
<td>DSNFMAS+</td>
<td>0.74</td>
<td>0.11</td>
<td>8</td>
<td>DSNFMAS+</td>
<td>0.74</td>
<td>0.11</td>
</tr>
</tbody>
</table>

a: Steps in stepwise rank regression analysis
b: Variables listed in order of selection in stepwise regression
c: Cumulative $R^2$ value with entry of each variable into regression model
d: Standardized rank regression coefficients (SRRCs) in final regression model

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0710PLOTSFIG.000 [DIRS 185207].
Figure K7.8.1-1[a]. Expected dose to RMEI ($\text{EXPDOSE}$, mrem/yr) over [0, 20,000 yr] for all radioactive species resulting from seismic fault displacement: (a) $\text{EXPDOSE}$ for all (i.e., 300) sample elements, (b) $\text{EXPDOSE}$ for first 50 sample elements, and (c) PRCCs for $\text{EXPDOSE}$.
Stepwise rank regression analyses and selected scatterplots for expected dose to RMEI (EXPDOSE, mrem/yr) over [0, 20,000 yr] for all radioactive species resulting from seismic fault displacement: (a) regressions for EXPDOSE at 3,000, 5,000, and 10,000 years, and (b,c,d) scatterplots for EXPDOSE at 10,000 years.
Figure K7.8.2-1[a]. Expected dose to RMEI (EXPDOSE, mrem/yr) over [0, 1,000,000 yr] for all radioactive species resulting from seismic fault displacement: (a) EXPDOSE for all (i.e., 300) sample elements, (b) EXPDOSE for first 50 sample elements, and (c) PRCCs for EXPDOS.
### Table 1

<table>
<thead>
<tr>
<th>Step</th>
<th>Variable</th>
<th>$R^2$</th>
<th>SRCC</th>
<th>Step</th>
<th>Variable</th>
<th>$R^2$</th>
<th>SRCC</th>
<th>Step</th>
<th>Variable</th>
<th>$R^2$</th>
<th>SRCC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>S2G2SPDM</td>
<td>0.25</td>
<td>0.51</td>
<td>1</td>
<td>S2G2SPDM</td>
<td>0.15</td>
<td>0.37</td>
<td>1</td>
<td>S2G2SPDM</td>
<td>0.18</td>
<td>0.40</td>
</tr>
<tr>
<td>2</td>
<td>INFIL</td>
<td>0.37</td>
<td>0.31</td>
<td>2</td>
<td>INFIL</td>
<td>0.29</td>
<td>0.40</td>
<td>2</td>
<td>INFIL</td>
<td>0.29</td>
<td>0.33</td>
</tr>
<tr>
<td>3</td>
<td>WPFLUX</td>
<td>0.43</td>
<td>0.22</td>
<td>3</td>
<td>WPFLUX</td>
<td>0.37</td>
<td>0.28</td>
<td>3</td>
<td>WPFLUX</td>
<td>0.38</td>
<td>0.36</td>
</tr>
<tr>
<td>4</td>
<td>EP1LOWPU</td>
<td>0.48</td>
<td>0.21</td>
<td>4</td>
<td>EP1LOWPU</td>
<td>0.44</td>
<td>0.28</td>
<td>4</td>
<td>EP1LOWPU</td>
<td>0.43</td>
<td>0.25</td>
</tr>
<tr>
<td>5</td>
<td>SEEPPRM</td>
<td>0.52</td>
<td>0.19</td>
<td>5</td>
<td>SEEPPRM</td>
<td>0.48</td>
<td>0.22</td>
<td>5</td>
<td>SEEPPRM</td>
<td>0.48</td>
<td>0.18</td>
</tr>
<tr>
<td>6</td>
<td>MICP237</td>
<td>0.55</td>
<td>0.18</td>
<td>6</td>
<td>MICP237</td>
<td>0.55</td>
<td>0.19</td>
<td>6</td>
<td>MICP237</td>
<td>0.52</td>
<td>0.20</td>
</tr>
<tr>
<td>7</td>
<td>CPUCOLWF</td>
<td>0.57</td>
<td>0.17</td>
<td>7</td>
<td>CPUCOLWF</td>
<td>0.57</td>
<td>0.17</td>
<td>7</td>
<td>CPUCOLWF</td>
<td>0.54</td>
<td>0.19</td>
</tr>
<tr>
<td>8</td>
<td>SZCOLRAL</td>
<td>0.60</td>
<td>0.15</td>
<td>8</td>
<td>SZCOLRAL</td>
<td>0.59</td>
<td>0.10</td>
<td>8</td>
<td>SZCOLRAL</td>
<td>0.57</td>
<td>0.17</td>
</tr>
<tr>
<td>9</td>
<td>S2FISPVD</td>
<td>0.62</td>
<td>0.16</td>
<td>9</td>
<td>S2FISPVD</td>
<td>0.60</td>
<td>0.11</td>
<td>9</td>
<td>S2FISPVD</td>
<td>0.60</td>
<td>0.17</td>
</tr>
<tr>
<td>10</td>
<td>S2EP2ONC</td>
<td>0.63</td>
<td>0.12</td>
<td>10</td>
<td>S2EP2ONC</td>
<td>0.62</td>
<td>0.11</td>
<td>10</td>
<td>S2EP2ONC</td>
<td>0.62</td>
<td>0.14</td>
</tr>
<tr>
<td>11</td>
<td>PHCSS</td>
<td>0.65</td>
<td>0.12</td>
<td>11</td>
<td>PHCSS</td>
<td>0.63</td>
<td>0.12</td>
<td>11</td>
<td>PHCSS</td>
<td>0.64</td>
<td>0.18</td>
</tr>
<tr>
<td>12</td>
<td>HFOSA</td>
<td>0.66</td>
<td>0.11</td>
<td>12</td>
<td>HFOSA</td>
<td>0.64</td>
<td>0.11</td>
<td>12</td>
<td>HFOSA</td>
<td>0.67</td>
<td>0.15</td>
</tr>
<tr>
<td>13</td>
<td>RUBMAX1</td>
<td>0.67</td>
<td>0.10</td>
<td>13</td>
<td>RUBMAX1</td>
<td>0.65</td>
<td>0.10</td>
<td>13</td>
<td>RUBMAX1</td>
<td>0.68</td>
<td>0.11</td>
</tr>
<tr>
<td>14</td>
<td>PHZMCONS</td>
<td>0.67</td>
<td>0.09</td>
<td>14</td>
<td>PHZMCONS</td>
<td>0.66</td>
<td>0.11</td>
<td>14</td>
<td>PHZMCONS</td>
<td>0.69</td>
<td>0.12</td>
</tr>
<tr>
<td>15</td>
<td>MICP239</td>
<td>0.67</td>
<td>0.17</td>
<td>15</td>
<td>MICP239</td>
<td>0.67</td>
<td>0.19</td>
<td>15</td>
<td>MICP239</td>
<td>0.70</td>
<td>0.10</td>
</tr>
<tr>
<td>16</td>
<td>UZFA4</td>
<td>0.68</td>
<td>0.11</td>
<td>16</td>
<td>UZFA4</td>
<td>0.68</td>
<td>0.11</td>
<td>16</td>
<td>UZFA4</td>
<td>0.71</td>
<td>0.10</td>
</tr>
</tbody>
</table>

### Figure K7.8.2-2[a]

Stepwise rank regression analyses and selected scatterplots for expected dose to RMEI ($EXPDOSE$, mrem/yr) over [0, 1,000,000 yr] for all radioactive species resulting from seismic fault displacement: (a) regressions for $EXPDOSE$ at 50,000, 200,000, and 500,000 years, and (b,c,d) scatterplots for $EXPDOSE$ at 500,000 years.

*Source:* Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0710PLOTSFIG.000 [DIRS 185207].

*NOTE:* In (c), the box extends from 0.25 to 0.75 quantile; lower and upper bar and whisker extend to 0.1 and 0.9 quantile, respectively; dots represent values outside 0.1 to 0.9 quantile range; median indicated by light horizontal line.

*MDL-WIS-PA-000005 REV 00 AD 01 FK-61[a]*
*March 2008*
Figure K8.1-1[a]. Expected dose to RMEI (EXPDOSE, mrem/yr) over [0, 20,000 yr] for all scenario classes obtained with version 5.005 of the TSPA-LA Model: (a) EXPDOSE for all (i.e., 300) sample elements, (b) EXPDOSE for first 50 sample elements, and (c) PRCCs for EXPDOSE.

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0710PLOTSFIG.000 [DIRS 185207].
Figure K8.1-2[a]. Stepwise rank regression analyses and selected scatterplots for expected dose to RMEI (EXPDOSE, mrem/yr) over [0, 20,000 yr] for all scenario classes obtained with version 5.005 of the TSPA-LA Model: (a) regressions for EXPDOSE at 3,000, 5,000, and 10,000 years, and (b,c,d) scatterplots for EXPDOSE at 10,000 years.

<table>
<thead>
<tr>
<th>Step</th>
<th>Variable</th>
<th>3,000 Years</th>
<th>5,000 Years</th>
<th>10,000 Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SCCTHRP</td>
<td>0.65</td>
<td>-0.72</td>
<td>-0.79</td>
</tr>
<tr>
<td>2</td>
<td>IGRATE</td>
<td>0.62</td>
<td>0.28</td>
<td>0.71</td>
</tr>
<tr>
<td>3</td>
<td>SZGWSPDM</td>
<td>0.67</td>
<td>0.21</td>
<td>0.74</td>
</tr>
<tr>
<td>4</td>
<td>INFL</td>
<td>0.71</td>
<td>0.19</td>
<td>0.76</td>
</tr>
<tr>
<td>5</td>
<td>MICTC99</td>
<td>0.73</td>
<td>0.15</td>
<td>0.78</td>
</tr>
<tr>
<td>6</td>
<td>SZFISPVO</td>
<td>0.75</td>
<td>0.14</td>
<td>0.79</td>
</tr>
<tr>
<td>7</td>
<td>MICC14</td>
<td>0.76</td>
<td>0.12</td>
<td>0.80</td>
</tr>
<tr>
<td>8</td>
<td>DSNMFMASS</td>
<td>0.77</td>
<td>0.10</td>
<td>0.81</td>
</tr>
<tr>
<td>9</td>
<td>UZFA8</td>
<td>0.78</td>
<td>-0.10</td>
<td>0.82</td>
</tr>
<tr>
<td>10</td>
<td>UZGAM</td>
<td>0.79</td>
<td>-0.09</td>
<td>0.82</td>
</tr>
<tr>
<td>11</td>
<td>SZDFCVO</td>
<td>0.79</td>
<td>-0.08</td>
<td>0.83</td>
</tr>
<tr>
<td>12</td>
<td>WFDFEEXF</td>
<td>0.80</td>
<td>0.08</td>
<td>0.83</td>
</tr>
<tr>
<td>13</td>
<td>KDUIMEC</td>
<td>0.80</td>
<td>0.08</td>
<td>0.84</td>
</tr>
<tr>
<td>14</td>
<td>MICPA231</td>
<td>0.81</td>
<td>-0.08</td>
<td>0.84</td>
</tr>
<tr>
<td>15</td>
<td>BCKRA226</td>
<td>0.85</td>
<td>-0.08</td>
<td></td>
</tr>
</tbody>
</table>

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0710PLOTSFIG.000 [DIRS 185207].
Expected dose to RMEI (EXPDOSE, mrem/yr) over [0, 1,000,000 yr] for all scenario classes obtained with version 5.005 of the TSPA-LA Model:
(a) EXPDOSE for all (i.e., 300) sample elements, (b) EXPDOSE for first 50 sample elements, and (c) PRCCs for EXPDOSE
Figure K8.2-2[a]. Stepwise rank regression analyses and selected scatterplots for expected dose to RMEI (EXPDOSE, mrem/yr) over [0, 1,000,000 yr] for all scenario classes obtained with version 5.005 of the TSQA-LA Model: (a) regressions for EXPDOSE at 50,000, 200,000, and 500,000 years, and (b,c,d) scatterplots for EXPDOSE at 500,000 years.

Source: Output DTNs: MO0710ADTSPANEO.000 [DIRS 183752]; and MO0710PLOTFIG.000 [DIRS 185207].
Figure K10-1[a]. Expected dose to RMEI (EXPDOSE, mrem/yr) over [200,000, 220,000 yr] resulting from human intrusion at 200,000 years obtained with version 5.005 of the TSPA-LA Model: (a) EXPDOSE for all (i.e., 300) sample elements, (b) EXPDOSE for first 50 sample elements, and (c) PRCCs for EXPDOSE.
### Figure K10-2[a]. Stepwise Rank Regression Analyses and Selected Scatterplots for Expected Dose to RMEI (EXPDOSE, mrem/yr) over [200,000, 220,000 yr] Resulting from Human Intrusion at 200,000 Years Obtained with Version 5.005 of the TSPA-LA Model:

- (a) Regressions for EXPDOSE at 201,000, 203,000, and 205,000 Years,
- (b,c,d) Scatterplots for EXPDOSE at 201,000 Years,
- (e,f,g) Scatterplots for EXPDOSE at 205,000 Years

#### Table: Stepwise Rank Regression Analyses

<table>
<thead>
<tr>
<th>Step</th>
<th>Variable</th>
<th>R²</th>
<th>SRRC</th>
<th>Variable</th>
<th>R²</th>
<th>SRRC</th>
<th>Variable</th>
<th>R²</th>
<th>SRRC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SZGWSPDM</td>
<td>0.20</td>
<td>0.45</td>
<td>MICTC99</td>
<td>0.15</td>
<td>0.44</td>
<td>MICTC99</td>
<td>0.33</td>
<td>0.58</td>
</tr>
<tr>
<td>2</td>
<td>INFIL</td>
<td>0.40</td>
<td>0.48</td>
<td>CSSPECISA</td>
<td>0.33</td>
<td>0.44</td>
<td>CSNFM200</td>
<td>0.38</td>
<td>0.22</td>
</tr>
<tr>
<td>3</td>
<td>CSSPECISA</td>
<td>0.54</td>
<td>0.41</td>
<td>SZFISPVO</td>
<td>0.40</td>
<td>0.26</td>
<td>INFIL</td>
<td>0.41</td>
<td>-0.18</td>
</tr>
<tr>
<td>4</td>
<td>SZFISPVO</td>
<td>0.61</td>
<td>0.28</td>
<td>SZGWSPDM</td>
<td>0.43</td>
<td>0.18</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>SZIPPOV</td>
<td>0.65</td>
<td>-0.20</td>
<td>CSNFM200</td>
<td>0.47</td>
<td>0.19</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>SDIFCV</td>
<td>0.68</td>
<td>-0.18</td>
<td>SDIFCV</td>
<td>0.50</td>
<td>-0.19</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>MICTC99</td>
<td>0.70</td>
<td>0.14</td>
<td>INFIL</td>
<td>0.51</td>
<td>-0.13</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>CSWFA4AC</td>
<td>0.71</td>
<td>0.11</td>
<td>_CSRINDPO</td>
<td>0.53</td>
<td>-0.11</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>PHCSS</td>
<td>0.72</td>
<td>-0.11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>EP1NP2O5</td>
<td>0.73</td>
<td>-0.10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>CSNFM200</td>
<td>0.73</td>
<td>0.10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>SZPORSAL</td>
<td>0.74</td>
<td>0.09</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>DIAZMCO</td>
<td>0.75</td>
<td>0.08</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Source:** Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0710PLOTFIG.000 [DIRS 185207].
Figure K10-2[a]. Stepwise rank regression analyses and selected scatterplots for expected dose to RMEI (EXPDOSE, mrem/yr) over [200,000, 220,000 yr] resulting from human intrusion at 200,000 years obtained with version 5.005 of the TSPA-LA Model:
(a) regressions for EXPDOSE at 201,000, 203,000, and 205,000 years, (b,c,d) scatterplots for EXPDOSE at 201,000 years, and (e,f,g) scatterplots for EXPDOSE at 205,000 years (continued)
Figure K10-3[a]. Expected dose to RMEI (EXPDOSE, mrem/yr) over [220,000, 1,000,000 yr] resulting from human intrusion at 200,000 years obtained with version 5.005 of the TSPA-LA Model: (a) EXPDOSE for all (i.e., 300) sample elements, (b) EXPDOSE for first 50 sample elements, and (c) PRCCs for EXPDOSE.

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0710PLOTSFIG.000 [DIRS 185207].
**Figure K10-4[a]**. Stepwise rank regression analyses and selected scatterplots for expected dose to RMEI (EXPDOSE, mrem/yr) over [220,000, 1,000,000 yr] resulting from human intrusion at 200,000 years obtained with version 5.005 of the TSPA-LA Model: (a) regressions for EXPDOSE at 240,000, 500,000, and 760,000 years, and (b,c,d,e) scatterplots for EXPDOSE at 500,000 years.
Figure K10-5[a]. Comparison of expected dose to RMEI (EXPDOSE, mrem/yr) over [200,000, 1,000,000 yr] resulting from human intrusion at 200,000 years obtained with versions 5.000 and 5.005 of the TSPA-LA Model at (a) 201,000, (b) 205,000, (c) 500,000, and (d) 1,000,000 years.

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0710PLOTSFIG.000 [DIRS 185207].
Figure K10-6[a]. Comparison of summary curves (i.e., mean and 0.05, 0.5, and 0.95 quantile) for expected dose to RMEI (EXPDOSE, mrem/yr) over [200,000, 1,000,000 yr] resulting from human intrusion at 200,000 years obtained with versions 5.000 and 5.005 of the TSPA-LA Model.

Source: Output DTNs: MO0710ADTSPAWO.000 [DIRS 183752]; and MO0710PLOTSFIG.000 [DIRS 185207].
APPENDIX M[a]
COMPARISON WITH ELECTRIC POWER RESEARCH INSTITUTE ANALYSIS
M1[a] INTRODUCTION

Appendix M[a] contains a minor change from the parent document to correct a reference to supporting documentation. The last paragraph in Section M3.3 of the parent document has been updated to correct the reference and is included in Section M3.3[a] of this addendum. The corrected paragraph should be substituted into the discussion presented in Appendix M of the parent document.

M2[a] TSPA CONCEPTUAL MODEL DESIGN

No change.

M3[a] TSPA NOMINAL SCENARIO COMPARISON

No change.

M3.1[a] UNSATURATED FLOW

No change.

M3.2[a] ENGINEERED BARRIER SYSTEM ENVIRONMENT

No change.

M3.3[a] WASTE PACKAGE AND DRIP SHIELD DEGRADATION

In the Electric Power Research Institute (EPRI) TSPA, the computed failure distributions curves for the nominal scenario for the WP are shown on Figure 5-7 in Apted and Ross (2005 [DIRS 182229]), indicating onset of WP failures before 100,000 years. The EPRI TSPA Analysis only considers 8,160 CSNF WPs, of which 5,304 WPs fail after one million years (Senger 2008 [DIRS 185124]). In the TSPA-LA Nominal Scenario Class, the probabilistic projections of WP breaches exhibit a few realizations with a stress corrosion cracking penetrating crack occurring before 100,000 years (Section 8.2.1[a]). However, as Figure 7.7.3-2[a] indicates the bulk of the WP failures occur after about 200,000 years with 6,256 WPs failed by one million years.
INTENTIONALLY LEFT BLANK
**P1[a]  INTRODUCTION**

The checking and review activities following the completion of the TSPA-LA Model (v5.000) identified several issues related to errors in implementation, identification of undocumented conservatisms, and updates to parameter values. A detailed discussion of these issues, including an evaluation of the expected impact to the mean annual dose, is included in Appendix P of the parent document. The impact assessment documented in Section P13.3 of the parent document has been updated and is included in Section P13[a] of this addendum. The remaining issue descriptions and impact analyses documented in the parent document are not repeated in this addendum.

The results described in this addendum were generated with TSPA-LA Model v5.005, an updated version of the TSPA-LA Model v5.000, unless otherwise indicated. TSPA-LA Model v5.005 addresses most of the items presented in Appendix P of the parent document; the items resolved in v5.005 are listed in Appendix P[a] of this addendum. The issues addressed in v5.005 are identified in two updated tables, Table P-6[a] and P-7[a]. These two tables comprise a summary of the changes between v5.000 and v5.005 of the TSPA-LA Model.

The discussion and impact assessment presented in Appendix P of the parent document for the remaining issues not addressed in v5.005 of the TSPA-LA Model, as indicated on Table P-7[a], are not repeated in this addendum, as the issue description and impact assessment (excluding Section P13, which is revised in this addendum) remain unchanged and apply equally to v5.005 of the TSPA-LA Model.

**P2[a]  INVENTORY AND SEEPAGE FRACTION**

**P2.1[a]  ISSUE**

Addressed in TSPA-LA Model v5.005.

**P2.2[a]  ISSUE DESCRIPTION**

No change.

**P2.3[a]  IMPACT ASSESSMENT**

No impact to TSPA-LA v5.005 results.

**P3[a]  WASTE PACKAGE DAMAGE FROM SEISMIC EVENTS**

**P3.1[a]  ISSUE**

Addressed in TSPA-LA Model v5.005.

**P3.2[a]  ISSUE DESCRIPTION**

No change.
P3.3[a] IMPACT ASSESSMENT
No impact to TSPA-LA v5.005 results.

P4[a] OUTER BARRIER FAILURE FLAG IN SEISMIC MODEL

P4.1[a] ISSUE
Addressed in TSPA-LA Model v5.005.

P4.2[a] ISSUE DESCRIPTION
No change.

P4.3[a] IMPACT ASSESSMENT
No impact to TSPA-LA v5.005 results.

P5[a] INVERT CHEMISTRY

P5.1[a] ISSUE
Addressed in TSPA-LA Model v5.005.

P5.2[a] ISSUE DESCRIPTION
No change.

P5.3[a] IMPACT ASSESSMENT
No impact to TSPA-LA v5.005 results.

P6[a] WELD VOLUME

P6.1[a] ISSUE
Addressed in TSPA-LA Model v5.005.

P6.2[a] ISSUE DESCRIPTION
No change.

P6.3[a] IMPACT ASSESSMENT
No impact to TSPA-LA v5.005 results.
P7[a]  CRACK FAILURE OPENING

P7.1[a]  ISSUE
Addressed in TSPA-LA Model v5.005.

P7.2[a]  ISSUE DESCRIPTION
No change.

P7.3[a]  IMPACT ASSESSMENT
No impact to TSPA-LA v5.005 results.

P8[a]  DEGRADATION START TIME

P8.1[a]  ISSUE
Addressed in TSPA-LA Model v5.005.

P8.2[a]  ISSUE DESCRIPTION
No change.

P8.3[a]  IMPACT ASSESSMENT
No impact to TSPA-LA v5.005 results.

P9[a]  THRESHOLD RUBBLE VOLUME

P9.1[a]  ISSUE
Addressed in TSPA-LA Model v5.005.

P9.2[a]  ISSUE DESCRIPTION
No change.

P9.3[a]  IMPACT ASSESSMENT
No impact to TSPA-LA v5.005 results.

P10[a]  UNINTENDED CORRELATION OF UNCERTAIN PARAMETERS

P10.1[a]  ISSUE
Addressed in TSPA-LA Model v5.005.
P10.2[a] ISSUE DESCRIPTION
No change.

P10.3[a] IMPACT ASSESSMENT
No impact to TSPA-LA v5.005 results.

P11[a] UNCERTAINTY IN URANIUM SOLUBILITY

P11.1[a] ISSUE
Addressed in TSPA-LA Model v5.005.

P11.2[a] ISSUE DESCRIPTION
No change.

P11.3[a] IMPACT ASSESSMENT
No impact to TSPA-LA v5.005 results.

P12[a] IONIC STRENGTH FOR HIGH-LEVEL WASTE GLASS DOMAIN

P12.1[a] ISSUE
Addressed in TSPA-LA Model v5.005.

P12.2[a] ISSUE DESCRIPTION
No change.

P12.3[a] IMPACT ASSESSMENT
No impact to TSPA-LA v5.005 results.

P13[a] EFFECT ON SEEPAGE FROM WASTE PACKAGE LENGTH CHANGE
The impact assessment documented in Section P13.3 of the parent document has been updated. Specifically, the last two paragraphs of the impact assessment have been revised, however, the entire section has been repeated and is included below in Section P13.3[a] of this addendum.

P13.1[a] ISSUE
No change.

P13.2[a] ISSUE DESCRIPTION
No change.
P13.3[a] IMPACT ASSESSMENT

The Seepage Model for Performance Assessment provides the mean and standard deviation of the distribution of seepage rates (kg/WP/yr) over a large range of capillary strengths, permeabilities, and percolation fluxes. The seepage dynamically linked library (DLL) used in the TSPA-LA Model uses these rates, along with percolation fields, thermal histories at each WP location, and sampled values for mean capillary strength and mean permeability, to determine seepage rates (kg/WP/yr) at each location and time in each realization, and computes the seepage fraction (fraction of WP locations at which seepage occurs) at each time in each realization.

The Seepage Model for Performance Assessment is a three-dimensional continuum representation of a fractured rock system used to calculate drift seepage at Yucca Mountain. The three-dimensional calculational domain for the model is 10-m high, 4-m wide, and 2.4384-m long (BSC 2004 [DIRS 167652], Figure 6-1). This domain takes advantage of model symmetry and spatial correlation lengths to represent a system based on a drift diameter of 5.5 m and a WP length of 5.1 m with a smaller domain. Rock above and around the drift is also represented in the model. Because the model uses a no-flow vertical boundary along the drift axis, and also only represents a part of the WP length, seepage rates from the model are scaled up by a factor of 4.183, which represents the ratio between the considered drift area (5.5 m × 5.1 m) and the modeled drift area ((5.5 m / 2)*2.4384 m).

The seepage rates for an average WP length of 5.614 m can be estimated by scaling the Seepage Model for Performance Assessment results for an average WP length of 5.0 m. As noted in Seepage Model for PA Including Drift Collapse (BSC 2004 [DIRS 167652]), the limited size of the calculational domain was chosen to allow for the use of a fine mesh at the same resolution as the Software Configuration Management, while containing a reasonable number of cells that would not make the computational time too long. The cell dimensions in the vertical plane perpendicular to the drift axis are 0.1 m by 0.1 m and cell lengths parallel to the drift axes are about 0.3 m each (BSC 2004 [DIRS 167652], Section 6.3.1). The vertical boundaries, perpendicular to the drift axis and along the drift centerline are appropriate due to symmetry. The main issue for a heterogeneous system is the domain length versus spatial correlation length (BSC 2004 [DIRS 167652], Section 6.3.1). The lengths of the flow domain in the direction of the drift axis (2.4384 m) and normal to the drift axis (4 m) are 8 times and 13 times the spatial correlation length (0.3 m), respectively. Since the length of the flow domain in the direction of the drift axis is 8 times the correlation length, the no flow boundaries perpendicular to the drift axis are considered appropriate, and should not have a significant effect on flow results. Because the no-flow boundaries have little effect on flow results, the model adequately represents any WP length longer than the model dimensions along the drift axis, as long as the results are scaled by the ratio of the chosen WP length to the modeled WP length. Thus, seepage rates for an average WP length of 5.614 m can be estimated by scaling the Seepage Model for Performance Assessment results for an average WP length of 5.0 m. This scaling would increase the mean and standard deviation of the distribution proportionally (by a factor of 5.614 / 5.1 = 1.10).

The seepage fraction is computed in the Seepage DLL as the fraction of locations at which seepage exceeds the threshold of 0.1 kg/WP/yr. Since seepage rates increase when the average WP length is increased, the seepage fraction may also increase, because the seepage rate at some locations may increase from just less than the threshold to greater than the threshold. Current
TSPA-LA software does not support a numerical evaluation of the degree to which the seepage fraction may increase when average WP length increases. To evaluate the potential impact on total dose associated with an increase in seepage fraction due to an increased WP length, the correlation between seepage fraction and expected annual dose was examined for the 1,000,000-year Nominal Modeling Case, the 10,000-year Seismic Ground Motion (GM) Modeling Case, and the 1,000,000-year Seismic GM Modeling Case. The 10,000-year Igneous Intrusion Modeling Case and the 1,000,000-year Igneous Intrusion Modeling Case which are also major contributors to dose were not examined because after an igneous event occurs, all WPs are evaluated in a seeping environment. For the three cases, scatter plots of expected annual doses versus seepage fraction at 10,000 or 1,000,000 years are presented along with the rank correlations of expected annual dose and seepage fraction at those times. As shown in Figure P-20[a], for the 1,000,000-year Nominal Modeling Case, negligible correlation between expected annual dose and seepage fraction at 1,000,000 years is seen. The rank correlation between expected annual dose and seepage fraction is $2.4 \times 10^{-2}$. Similarly, for the 10,000-year Seismic GM Case, negligible correlation between expected annual dose and seepage fraction at 10,000 years is seen (Figure P-21(a)[a]). The rank correlation between expected annual dose and seepage fraction, for the 10,000-year Seismic GM Case, is $4.65 \times 10^{-2}$. For the 1,000,000-year Seismic Ground Motion Case, negligible correlation between expected annual dose and seepage fraction at 1,000,000 years is seen (Figure P-21(b)[a]). The rank correlation between expected annual dose and seepage fraction, for the 1,000,000-year Seismic GM Case, is $1.17 \times 10^{-2}$. Based on the negligible correlation between expected annual dose and seepage fraction shown in these analyses, it is assumed that change in seepage fractions, associated with an increase in the waste package length to 5.614 m, will have little impact on total dose.

Because seepage rates increase proportionally with increased WP length, and seepage fraction is not anticipated to have a large impact on dose, the net effect of increasing WP length on annual dose is to increase seepage rates in a percolation bin by approximately 10 percent. As demonstrated in Section P17, annual dose may increase in proportion to changes in seepage rates for cases where the major dose-controlling radionuclide is solubility-controlled in the EBS. For radionuclides that do not have solubility limits, the increased seepage flux would have negligible impact on the mass flux. Therefore, the overall effect of increasing the average WP length used in the seepage abstraction by 10 percent would be minor.

**P14[a] IGNEOUS EVENT PROBABILITY**

**P14.1[a] ISSUE**

No change.

**P14.2[a] ISSUE DESCRIPTION**

No change.

**P14.3[a] IMPACT ASSESSMENT**

No change.
P15[a] LONGITUDINAL DISPERSIVITY IN 1-D SZ TRANSPORT MODEL

P15.1[a] ISSUE
Addressed in TSPA-LA Model v5.005.

P15.2[a] ISSUE DESCRIPTION
No change.

P15.3[a] IMPACT ASSESSMENT
No impact to TSPA-LA v5.005 results.

P16[a] GLASS DEGRADATION RATE

P16.1[a] ISSUE
Addressed in TSPA-LA Model v5.005.

P16.2[a] ISSUE DESCRIPTION
No change.

P16.3[a] IMPACT ASSESSMENT
No impact to TSPA-LA v5.005 results.

P17[a] SEEPAGE FLUX AFTER DRIFT COLLAPSE

P17.1[a] ISSUE
No change.

P17.2[a] ISSUE DESCRIPTION
No change.

P17.3[a] IMPACT ASSESSMENT
No change.

P18[a] UNSTABLE IRON OXYHYDROXIDE COLLOIDS

P18.1[a] ISSUE
Addressed in TSPA-LA Model v5.005.
P18.2[a] ISSUE DESCRIPTION
No change.

P18.3[a] IMPACT ASSESSMENT
No impact to TSPA-LA v5.005 results.

P19[a] DOE SPENT NUCLEAR FUEL MASS RELEASE

P19.1[a] ISSUE
Addressed in TSPA-LA Model v5.005.

P19.2[a] ISSUE DESCRIPTION
No change.

P19.3[a] IMPACT ASSESSMENT
No impact to TSPA-LA v5.005 results.

P20[a] GOLDSIM SOFTWARE ERROR

P20.1[a] ISSUE
Addressed in TSPA-LA Model v5.005.

P20.2[a] ISSUE DESCRIPTION
No change.

P20.3[a] IMPACT ASSESSMENT
No impact to TSPA-LA v5.005 results.

P21[a] UNSATURATED ZONE TRANSPORT THROUGH FAULT ZONE

P21.1[a] ISSUE
No change.

P21.2[a] ISSUE DESCRIPTION
No change.

P21.3[a] IMPACT ASSESSMENT
No change.
P22[a] OTHER MINOR IMPLEMENTATION ERRORS

P22.1[a] ISSUE
Addressed in Table P-6[a].

P22.2[a] ISSUE DESCRIPTION
No change.

P23[a] SUPERFICIAL CHANGES

P23.1[a] ISSUE
No change.

P23.2[a] ISSUE DESCRIPTION
No change.

P23.3[a] IMPACT ASSESSMENT
No change.

P24[a] SUMMARY

The issues addressed in TSPA-LA Model v5.005 which were presented in Appendix P of the parent document are summarized in Table P-7[a]. Since most of the issues evaluated had a negligible to small impact (except for the issue discussed in Section P3), the combined effect of correcting the issues was small for mean annual dose for all modeling cases (as documented in Section 7.3.1[a]). In none of the issues evaluated does the mean annual dose increase appreciably above the base-case results presented in Section 8 of the parent document, in fact, in most cases, it decreases (see Section 7[a] and Section 8[a] of this addendum). Thus, the impact assessments presented in Appendix P of the parent document were accurate and the validation activities performed on the results documented therein remain applicable.
INTENTIONALLY LEFT BLANK
<table>
<thead>
<tr>
<th>ISSUE DESCRIPTION</th>
<th>ANTICIPATED IMPACT (V5.000)</th>
<th>ADDRESSED V5.005</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Drift-wall condensation incorrectly turned off in the non-dripping environments.</td>
<td>This error should have negligible or no impact in all modeling cases. Because drift-wall condensation occurs for at most 2,000 years (Section 6.3.3.2.2) and because the DS remains intact throughout this period in all modeling cases except Drip Shield EF Modeling Case, the release from any failed WP should be negligibly impacted. In the Drip Shield EF Modeling Case since the WP is always modeled to be located in the dripping environment (Section 6.4.1.3), there should be no impact.</td>
<td>Yes – Drift wall condensation appropriately applied to the non-dripping environments.</td>
</tr>
<tr>
<td>2 Inconsistent half-lives especially for $^{79}\text{Se}$ and $^{126}\text{Sn}$ between those applied in GoldSim and those used by the UZ and SZ transport models implemented using DLLs.</td>
<td>The $^{79}\text{Se}$ half-life in GoldSim is set at 290,000 years while that in the UZ and SZ transport model is set at 296,000 years. The $^{126}\text{Sn}$ half-life in GoldSim is set at 230,000 years while that in the UZ and SZ transport model is set at 250,000 years. These inconsistencies are minor, as they occur only in the second significant digit. Since the dose contribution from $^{79}\text{Se}$ and $^{126}\text{Sn}$ is at least an order of magnitude lower than some of the other radionuclides (see Figures P-1 to P-5), the impact on the mean annual dose would be negligible.</td>
<td>Yes – EBS, Unsaturated Zone, and Saturated Zone submodels use the same half-life values.</td>
</tr>
<tr>
<td>3 In the calculations to determine the time of first seismic damage to the WP, the abstraction for WP failure under intact DS is considered while the DS is intact. This calculation should not be used after either the DS plate or DS framework has failed. However, this calculation ignores the DS framework failure and only considers the DS plate failure to determine whether to use this abstraction or not.</td>
<td>It should be noted that this error only affects the 1,000,000-year Seismic GM Modeling Case because the DS remains intact in the 10,000-year modeling case. Since the DS framework failure (average failure time of 100,000 years) occurs earlier than the DS plate failure (average failure time of 250,000 years), there is a possibility of predicting the WP failure time earlier than intended in the time duration where the DS framework has failed but the DS plate is intact. This error may have an impact on estimating first failure time for only CDSP WPs as the probability of WP failure under intact DS is generally greater than the probability of failure under failed DS that is surrounded by rubble. Even here, the probability of occurrence of this error is small, as the DS framework lasts up to 100,000 years on an average, during which time CDSP WPs that are likely to fail from seismic damage would have failed in a majority of the realizations (~70%). For CSNF WPs there is no impact anticipated, as the probability of failure under intact DS is much smaller than the probability of failure under the failed DS that is surrounded by rubble. As a result, this error is likely to have only a negligible impact on the mean annual dose.</td>
<td>Yes – Corrected to consider both the DS plate and framework failures.</td>
</tr>
<tr>
<td>4 The calculation for the time of first seismic damage may be incorrect if the WP damage is from the first seismic event.</td>
<td>This error only appears when the first seismic event causes the damage to the WP or leads to rockfall. Since seismic events occur on an average of every 2,330 years (inverse of specified annual rate of 4.287 $\times 10^{-5}$ yr$^{-1}$), only those realizations would be impacted where the WP damage or rockfall occurs within 2,330 years (on an average). There are only five such realizations in the 9,000 realization seismic ground motion base case where the damage should have occurred from the first seismic event but did not occur due to the error. The impact of this error is negligible. No other modeling cases are affected.</td>
<td>Yes – Calculation was corrected to accurately reflect the first seismic event.</td>
</tr>
<tr>
<td>ISSUE DESCRIPTION</td>
<td>ANTICIPATED IMPACT (V5.000)</td>
<td>ADDRESSED V5.005</td>
</tr>
<tr>
<td>----------------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>5 The HLW glass derived waste form colloid concentrations are overestimated under conditions when the waste form colloids are unstable.</td>
<td>This error occurs only when the conditions are unstable for the generation of glass waste form colloids. Since the maximum concentration of HLW glass waste form colloids, under stable conditions, is itself small (maximum of 2 mg/L and a mean of 0.3 mg/L) the mass transported on colloids will be negligibly small compared to that transported in the dissolved phase. Thus, this overestimation would have negligible impact on the mean annual dose. Furthermore, the unstable conditions generally occur when the ionic strength is greater than 0.4 mol/kg, which is typical while there is no flow through the WP. Since the transport mechanism is diffusion when there is no flow and because the diffusion coefficient of colloids is much smaller compared to the dissolved species (by at least two orders) no appreciable mass can be carried by the colloids.</td>
<td>Yes – High-level radioactive waste glass colloid concentration calculation was corrected.</td>
</tr>
<tr>
<td>6 The element that integrates the mass released from the WP in the Human Intrusion Scenario integrates the mass flux rate computed for the previous timestep over the next timestep using the next timestep length. It should instead integrate the mass flux rate computed for the given timestep over that timestep length.</td>
<td>This error would only have an impact when the timestep length is changing as the integrated mass would change. Since the intrusion time is set at 200,000 years in the Human Intrusion Scenario and because there is no change made in the timestep length for the remaining simulation duration, the calculations are not affected. The only impact is one timestep delay in passing the mass to the UZ borehole pathway while the dose magnitudes remain unaffected. Since this is a highly stylized modeling case, with a selected intrusion time, the one timestep delay is not important to the overall system results and does not affect the dose values.</td>
<td>Yes – The calculation has been corrected to use the appropriate timestep length.</td>
</tr>
<tr>
<td>ISSUE DESCRIPTION</td>
<td>ANTICIPATED IMPACT (V5.000)</td>
<td>ADDRESSED</td>
</tr>
<tr>
<td>-------------------</td>
<td>---------------------------</td>
<td>------------</td>
</tr>
<tr>
<td><strong>7</strong> The implemented range of two uncertain parameters used in determining the number of monolayers of adsorbed water for corrosion products as part of the EBS Transport submodel is different from their intended ranges.</td>
<td>The stochastic elements FHH_Isotherm_k_CP_a and FHH_Isotherm_s_CP_a are sampled to determine the value for parameters k and s that are used in the water adsorption isotherm for corrosion products to determine the number of sorbed layers of water (SNL 2007 [DIRS 177407], Section 6.3.4.3.2), which is eventually used in computing the saturation under conditions when there is no flow through the WP. The uniform distribution ranges used from EBS Radionuclide Transport Abstraction, (SNL 2007 [DIRS 177407], Table 8.2-4) are: FHH_Isotherm_k_CP_a: 1.048 – 1.370 FHH_Isotherm_s_CP_a: 1.525 – 1.852 The correct ranges, as intended in Section 6.3.4.3.2 of EBS Radionuclide Transport Abstraction (SNL 2007 [DIRS 177407]) are: FHH_Isotherm_k_CP_a: 1.030 – 1.326 FHH_Isotherm_s_CP_a: 1.493 – 1.799 The difference in the two ranges is small compared to their uncertainty ranges and thus the effect on calculating the number of monolayers of adsorbed water and saturation of corrosion products is likely to be negligible, leading to negligible impact on the mean annual dose.</td>
<td>Yes – Uncertainty distributions have been corrected.</td>
</tr>
<tr>
<td><strong>8</strong> The $K_d$ range for sorption of Np on the Uranium mineral colloids in the EBS is not correct.</td>
<td>The $K_d$ range for sorption of Np on the uranium colloids is given by a log-uniform distribution ranging from 10 to 500 mL/g (Table 6.3.7-64). The lower bound value of 10 mL/g was incorrectly set to 1 mL/g during the implementation. The impact of this reduction in the lower bound is anticipated to be negligible as the Np mass carried by the uranium colloids is likely to be small (even with the corrected values) compared to the mass carried by other colloid types and in the dissolved phase. Considering the mean uranium colloid concentration of about 6 mg/l (based on cumulative distribution function given in Table 6.3.7-64) and the maximum Np $K_d$ of 500 mL/g, and multiplying the two would lead to a value of about $3 \times 10^{-3}$, which represents the ratio of Np mass on the uranium colloids to the mass in the dissolved phase in given water volume. This indicates that the predominant mechanism for Np transport is in the dissolved phase. The impact of this error is anticipated to be negligible, if any, on the mean annual dose.</td>
<td>Yes – $K_d$ range for sorption of Np on the uranium colloids has been corrected.</td>
</tr>
<tr>
<td>ISSUE DESCRIPTION</td>
<td>ANTICIPATED IMPACT (V5.000)</td>
<td>ADDRESSED</td>
</tr>
<tr>
<td>---------------------------------------------------------------------------------</td>
<td>-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>-------------</td>
</tr>
<tr>
<td>9 In the Human Intrusion Modeling Case, the mass irreversibly associated with</td>
<td>In the Human Intrusion Modeling Case, the mass irreversibly associated with the waste form colloids (referred as &quot;Ic&quot;) and the iron oxyhydroxide colloids (referred as &quot;If&quot;) from the WP and passed through the UZ borehole needs to be combined together and repartitioned based on the fast fraction, before passing the mass to the SZ. This needs to be done in such a way that only a small fraction (0.00168) travels unretarded (fast) while the rest of the mass travels with some retardation (slowly). The impact of this error is anticipated to be small as the relative contribution from the fast and slow traveling mass fractions cannot be fully differentiated due to large timesteps employed in the TSPA-LA Model past 200,000 years (when the human intrusion is modeled). Thus, even though the relative contribution of Ic and If species could vary, the combined mass flux from the mass irreversibly associated with colloids is not anticipated to change. As a result, the impact on the mean annual dose is anticipated to be negligible.</td>
<td>Yes – Human Intrusion Scenario Modeling Case was corrected to include a partitioning of the mass released to the SZ between fast and slow colloid fractions.</td>
</tr>
<tr>
<td>colloids that is released to the SZ is not partitioned into the fast transport</td>
<td></td>
<td></td>
</tr>
<tr>
<td>fraction and the slow transport fraction.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 In the UZ transport model, the correct minimum value for the selenium $K_d$ for vitric rock units was supposed to be 0 mL/g. However, the minimum value after natural log transformation was set to 0, which is equivalent to a $K_d$ of 1 mL/g.</td>
<td>The impact of this error is anticipated to be negligible as the mean $K_d$ value remains largely unchanged (reduced by 0.8%) when the minimum value is corrected. Furthermore, $^{79}$Se is not a large contributor to dose.</td>
<td>Yes – The selenium $K_d$ for vitric rock has been corrected.</td>
</tr>
<tr>
<td>For the UZ transport model, the uranium $K_d$ for zeolitic rock unit has an error</td>
<td>The impact of this error is anticipated to be negligible as the mean $K_d$ value would change from 5.25 mL/g to 7.75 mL/g. This small increase is unlikely to affect the transport of uranium through the UZ. Furthermore, the current error is conservative as it leads to lowering the uranium $K_d$ in the UZ matrix.</td>
<td>Yes – The uranium $K_d$ for zeolitic rock has been corrected.</td>
</tr>
<tr>
<td>at probability level of 1. It was incorrectly set to 20 mL/g instead of 30 mL/g.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 The concentration limit for plutonium and americium mass irreversibly sorbed on</td>
<td>The error would only have an impact if the irreversible colloid concentration in the invert is nearing the concentration limit in the invert, which is an unlikely condition due to fast transport rates out of the invert compared to the incoming transport rate. Even if the conditions conducive to error occur, they would remain for a short time period compared to the simulation time. The impact of this error is expected to be negligible on the mean annual dose.</td>
<td>Yes – The calculation has been corrected to use the stability criteria in the corrosion products domain.</td>
</tr>
<tr>
<td>the iron oxyhydroxide colloids in the invert is incorrectly based on the stability criteria for the waste form domain instead of the corrosion products domain.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ISSUE DESCRIPTION</td>
<td>ANTICIPATED IMPACT (V5.000)</td>
<td>ADDRESSED V5.005</td>
</tr>
<tr>
<td>-------------------</td>
<td>-----------------------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>13 The time-dependent increase in the diffusive area from nominal corrosion processes (by SCC or general corrosion) on the WP outer barrier should be removed from the Human Intrusion Modeling Case.</td>
<td>Ignoring the time-dependent increase in diffusive area from nominal corrosion processes (by SCC or general corrosion) on the WP outer barrier is unlikely to affect the diffusive release out of the WP as only about 5% of the realizations would have SCC failures by 200,000 years, the time when the human intrusion event is modeled. Following the event, the patch area equal to the drill stem area is applied to the WP for both diffusive and advective release. The patch area applied is large enough to cause large diffusive releases. Since the general corrosion patches do not occur until very late times (&gt;400,000 years), any small increases in diffusive area from SCCs is unlikely to affect the diffusive flux. The impact of this error is likely to be negligibly small on the mean annual dose.</td>
<td>Yes – The nominal corrosion processes have been removed from the diffusive area calculation in the Human Intrusion Scenario.</td>
</tr>
<tr>
<td>14 In calculating the first damage time for the WP due to seismic ground motion, the possibility of failure from puncture was not considered.</td>
<td>The first damage time calculations only evaluate the failures caused by seismic-induced SCCs or by nominal corrosion processes (nominal SCC or general corrosion). However, there is a small probability that punctures could occur earlier under certain conditions. The conditions for puncture failure require that the DSs have failed and the WPs are surrounded by rubble. Under these conditions the probability of puncture varies as a function of PGV, but the probabilities remain low even at high PGVs (Figure 6.6-17). First failures from puncture damage are only likely to occur late in time when the WP has a reduced thickness (Figure 7.3.2-15). The number of realizations where puncture occurs before seismic-induced SCCs would be small since there is a higher probability of damage from seismic-induced SCCs (Figure 6.6-15). Note that this error only occurs in the Seismic GM Modeling Case run for 1,000,000 years. There is no effect on the Seismic GM Modeling Case run for 10,000 years as the conditions conducive to puncture do not occur. Analysis of a stand-alone model for WP degradation that includes both nominal and seismic degradation processes (output DTN: MO0709TSPAWPDS.000 [DIRS 183170]; file v5.000_GS_9.60.100_StandAlone_9krlz.gsm in folder Seismic_9k_Rlz) showed that 63 out of 9,000 realizations could have first damage from punctures. The impact of this on the mean annual dose is likely to be negligible as only 0.7% of the realizations would be affected and the effects are likely to be late (after the DSs are failed and the WPs have thinned).</td>
<td>Yes – Corrected the first damage calculation to include puncture failures during a seismic event.</td>
</tr>
</tbody>
</table>
15 The temperature and relative humidity modifications may be incorrectly applied after rubble fills the drifts as a result of degradation due to seismic ground motion. The percolation subregion representative temperature and relative humidity time histories under nominal conditions (from MSTHM abstraction) are modified once the drifts become filled with rubble as a result of drift degradation from seismic ground motion. These modifications (deltas) are applied by adding to or subtracting from the representative temperature and relative humidity datasets. Twelve possible delta combinations, from four infiltration scenarios over three host-rock thermal conductivity cases (Section 6.3.2.2), are considered in the TSPA-LA Model for each percolation subregion and for each fuel type. However, in order to limit the computational burden, only eight delta combinations are actually calculated: six delta combinations for CSNF and two delta combinations for HLW. The six delta combinations for CSNF are then mapped to 12 possible delta combinations for the CSNF fuel type in each percolation subregion. Similarly, the two delta combinations for HLW are then mapped to 12 possible delta combinations for the HLW fuel type (CDSP WP) for each percolation subregion.

Due to an implementation error, some of the combinations are incorrectly matched and the data are incorrectly read from the look-up tables. This could sometimes result in incorrect modifications of representative temperature and relative humidity time histories for the given percolation subregion and a given fuel type. In addition, some of the data sets used in the modification of temperatures (called temperature deltas) have been entered in a sequence that is different compared to the relative humidity deltas resulting in internal inconsistency once the modifications are made.

Note that the error is only possible in the two modeling cases in which rubble fills the drifts, the Seismic GM Modeling Case run for 1,000,000 years and the Seismic FD Modeling Case. The impact of this error on the mean annual dose for either modeling case is likely to be negligible as the variation in the delta among various combinations is small. Thus, even though incorrect values may be applied, they would not result in any appreciable deviations from the corrected time history profiles. Furthermore, the magnitude of the modification is itself small relative to the actual temperature and relative humidity values even at the maximum initial values (the magnitudes of the deltas decrease with time). As a result, the downstream models affecting radionuclide transport are unlikely to be appreciably impacted by this error.

The impact of the error on localized corrosion initiation is also evaluated based on the Localized Corrosion Initiation Uncertainty Analysis described in Appendix O. The five realizations (out of 300) that have early rubble fill times (within 12,000 years) all have conditions that are not conducive to localized corrosion initiation, even accounting for slightly incorrect temperature and relative humidity. One realization (realization 142), which has conditions favorable for localized corrosion until 12,000 years, has a rubble fill time greater than 100,000 years, by which time localized corrosion is not favored. It is concluded that there is no impact of this error on the localized corrosion initiation.

<table>
<thead>
<tr>
<th>ISSUE DESCRIPTION</th>
<th>ANTICIPATED IMPACT (V5.000)</th>
<th>ADDRESSED V5.005</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>The temperature and relative humidity modifications may be incorrectly applied after rubble fills the drifts as a result of degradation due to seismic ground motion. The percolation subregion representative temperature and relative humidity time histories under nominal conditions (from MSTHM abstraction) are modified once the drifts become filled with rubble as a result of drift degradation from seismic ground motion. These modifications (deltas) are applied by adding to or subtracting from the representative temperature and relative humidity datasets. Twelve possible delta combinations, from four infiltration scenarios over three host-rock thermal conductivity cases (Section 6.3.2.2), are considered in the TSPA-LA Model for each percolation subregion and for each fuel type. However, in order to limit the computational burden, only eight delta combinations are actually calculated: six delta combinations for CSNF and two delta combinations for HLW. The six delta combinations for CSNF are then mapped to 12 possible delta combinations for the CSNF fuel type in each percolation subregion. Similarly, the two delta combinations for HLW are then mapped to 12 possible delta combinations for the HLW fuel type (CDSP WP) for each percolation subregion. Due to an implementation error, some of the combinations are incorrectly matched and the data are incorrectly read from the look-up tables. This could sometimes result in incorrect modifications of representative temperature and relative humidity time histories for the given percolation subregion and a given fuel type. In addition, some of the data sets used in the modification of temperatures (called temperature deltas) have been entered in a sequence that is different compared to the relative humidity deltas resulting in internal inconsistency once the modifications are made. Note that the error is only possible in the two modeling cases in which rubble fills the drifts, the Seismic GM Modeling Case run for 1,000,000 years and the Seismic FD Modeling Case. The impact of this error on the mean annual dose for either modeling case is likely to be negligible as the variation in the delta among various combinations is small. Thus, even though incorrect values may be applied, they would not result in any appreciable deviations from the corrected time history profiles. Furthermore, the magnitude of the modification is itself small relative to the actual temperature and relative humidity values even at the maximum initial values (the magnitudes of the deltas decrease with time). As a result, the downstream models affecting radionuclide transport are unlikely to be appreciably impacted by this error. The impact of the error on localized corrosion initiation is also evaluated based on the Localized Corrosion Initiation Uncertainty Analysis described in Appendix O. The five realizations (out of 300) that have early rubble fill times (within 12,000 years) all have conditions that are not conducive to localized corrosion initiation, even accounting for slightly incorrect temperature and relative humidity. One realization (realization 142), which has conditions favorable for localized corrosion until 12,000 years, has a rubble fill time greater than 100,000 years, by which time localized corrosion is not favored. It is concluded that there is no impact of this error on the localized corrosion initiation.</td>
<td>No – Impact summary as assessed for v5.000.</td>
</tr>
<tr>
<td>ISSUE DESCRIPTION</td>
<td>ANTICIPATED IMPACT (V5.000)</td>
<td>ADDRESSED V5.005</td>
</tr>
<tr>
<td>-------------------</td>
<td>-----------------------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>16 Drift-wall condensation flux is being applied even after the igneous intrusive event, when the drifts are all assumed to be filled with magma.</td>
<td>The drift-wall condensation model is applicable only under nominal conditions and does not apply once the drifts are degraded from seismic ground motion or filled with magma following the igneous intrusion. However, it is being incorrectly applied even after the igneous intrusion. The impact of the error is restricted to the first 2,000 years only because the drift-wall condensation can only occur in the first 2,000 years (Section 6.3.3.2.2). As a result, the water flux through the WP could be higher than the percolation flux leading to increased advective mass flux of radionuclides for realizations when the igneous intrusion occurs within the first 2,000 years. But because the probability of having an igneous event in the first 2,000 years is negligibly small (mean value of $3.3 \times 10^{-5}$) the effect on expected dose of this additional mass flux is small. The impact of the error is evaluated to be negligible.</td>
<td>Yes – Drift wall condensation flux was turned off after an igneous intrusion event.</td>
</tr>
</tbody>
</table>
Table P-6[a]. Discussion of Other Minor Implementation Errors (Continued)

<table>
<thead>
<tr>
<th>ISSUE DESCRIPTION</th>
<th>ANTICIPATED IMPACT (V5.000)</th>
<th>ADDRESSED V5.005</th>
</tr>
</thead>
<tbody>
<tr>
<td>17 The WP temperatures could sometimes fall below the lower range of validity of the abstractions provided for computing in-package chemistry, HLW glass degradation rate, and dissolved concentration limits in the TSPA-LA Model.</td>
<td>An assessment of the range of validity shows that most of the validity ranges specified for the process models and abstractions included in the TSPA-LA Model are honored (see output DTN: MO0709TSPALAMO.000 [DIRS 182981]). However for three submodels (discussed below) that are included in the 1,000,000-year performance calculations the representative WP temperatures could fall below the lower limit specified by the abstractions; the minimum waste package temperature noted in the TSPA-LA Model is about 17°C for the 1,000,000-year simulation period. The lower temperature limit for the range of applicability of the In-Package Chemistry Abstraction (SNL 2007 [DIRS 180506]) is 25°C. Without an alternate implementation for low temperature conditions, the TSPA-LA Model applies the In-Package Chemistry Abstraction at temperatures below 25°C. Given that the In-Package Chemistry Abstraction for pH and ionic strength includes uncertainty to account for higher temperatures, the application of abstraction at lower temperatures is anticipated to produce results that are within the range of uncertainty captured in the abstractions for pH and ionic strength. The lower temperature limit for the range of applicability of the HLW Glass Waste Form Degradation Abstraction (BSC 2004 [DIRS 169988]) is 20°C. Without an alternate implementation for low temperature conditions, the TSPA-LA Model applies the HLW glass waste form degradation rate model at temperatures below 20°C. The lower temperature limit was determined by the ranges considered in the experimental results used to validate the rate model (BSC 2004 [DIRS 169988], Section 7.3) which showed that the Arrhenius relationship for glass degradation rate is maintained between 20°C and 90°C. This relationship is not anticipated to change between 17°C and 20°C and therefore unlikely to have any effect on mass transport calculations. The lower temperature limit for the range of applicability of the Dissolved Concentration Limits Abstraction (SNL 2007 [DIRS 177418]) is 25°C. Without an alternate implementation for low temperature conditions, the TSPA-LA Model applies the Dissolved Concentration Limits Abstraction at temperatures below 25°C. Because actinides have retrograde solubility (SNL 2007 [DIRS 177418], Section 6.3.3.3), it is possible that dissolved concentration limits below 25°C could be higher than those implemented in the TSPA-LA Model. But because the Dissolved Concentration Limits Abstraction includes additional uncertainty to account for differences in temperature conditions (SNL 2007 [DIRS 177418], Section 6.3.3), it is anticipated that any small effects from extrapolation would produce results that are within the range of uncertainty captured in the abstractions for dissolved concentration limits. For the 10,000 year simulations the temperatures remain within the range of validity.</td>
<td>No – Impact summary as assessed for v5.000.</td>
</tr>
</tbody>
</table>
### Table P-6[a]. Discussion of Other Minor Implementation Errors (Continued)

<table>
<thead>
<tr>
<th>ISSUE DESCRIPTION</th>
<th>ANTICIPATED IMPACT (V5.000)</th>
<th>ADDRESSED V5.005</th>
</tr>
</thead>
<tbody>
<tr>
<td>18 Drift-wall condensation flow only occurs in the non-lithophysal regions of the repository.</td>
<td>The drift wall condensation abstraction states that drift wall condensation should cease after the drift has collapsed. Drift collapse is only modeled in the Seismic Scenario Class. In the Seismic Scenario Class, drift collapse occurs in the lithophysal regions of the repository; thus the fraction of WPs that are exposed to drift wall condensation is limited to the fraction of WPs in the non-lithophysal region. However, this limit was not properly implemented in the TSPA-LA Model. As a result, in all but the Igneous Intrusion modeling case, drift wall condensation was limited to the fraction of WPs in the non-lithophysal region and therefore was underestimated in the TSPA-LA Model. Because drift wall condensation only increases the flux in the repository for the first 2,000 years, the dose impact can only occur in the modeling cases that fail WPs in the first 2,000 years and have radionuclide transport in the first 2,000 years. The implementation is correct for the Seismic Ground Motion and Seismic Fault Displacement modeling cases and the Igneous Intrusion Modeling Case. The Nominal Scenario Class and Human Intrusion Scenario do not have failures in the first 2,000 years and thus are not affected. The EF WP modeling case does have WP failures in the first 2,000 years, but the DS remains intact so any additional condensation flux is not anticipated to change transport out of the EF WP. The flux through a failed WP in the EF DS modeling case could be increased by drift wall condensation. As a result, WP releases could also be increased, leading to a higher expected dose in the EF DS modeling case. Contributing less than 2.5% to the total mean dose, the EF DS modeling case is not a significant contributor to the total dose from the repository. The impact of the error is evaluated to be negligible. No – Impact summary as assessed for v5.000.</td>
<td></td>
</tr>
<tr>
<td>19 Mass of iron oxyhydroxide colloids computed for Cell 1 is used in the preliminary forward rate constant calculation for americium in Cell 2 of the EBS Transport Submodel for CSNF WP.</td>
<td>A preliminary calculation to determine the forward rate constant for implementing kinetic sorption of americium on iron oxyhydroxide colloids and stationary corrosion products for CSNF WP incorrectly uses the mass of iron oxyhydroxide colloids from Cell 1 of the EBS Transport Submodel. It should instead use the mass of iron oxyhydroxide colloids from Cell 2 because the sorption calculation is relevant to Cell 2 (corrosion products domain) of the EBS transport submodel. The impact of this error is anticipated to be negligible because it is used only in the preliminary calculation of the forward rate constant for americium. It is considered a final value only if certain constraints are met based on the stability of iron oxyhydroxide colloids and flow rates. In no case can it result in forward rate constant value outside the experimentally determined range. Because the bulk forward reaction rates are generally large (compared to the time step size), any small changes in the forward rate constant are likely to have negligible impact on the bulk reaction rates and consequently on the mass kinetically sorbed. The overall impact of the error is anticipated to be negligible, if any. No</td>
<td></td>
</tr>
</tbody>
</table>

Note: Table continues on the next page.
<table>
<thead>
<tr>
<th>Issue No.</th>
<th>Issue Description</th>
<th>Anticipated Impact</th>
<th>Addressed in v5.005</th>
</tr>
</thead>
<tbody>
<tr>
<td>P2.</td>
<td>Inventory for $^{36}$Cl, $^{79}$Se, and $^{126}$Sn was omitted in the 10,000-year simulation modeling cases and the seepage fractions applied for the 10,000-year simulations are based on the post-10,000-year climate.</td>
<td>Negligible</td>
<td>Yes – Added $^{36}$Cl, $^{79}$Se, and $^{126}$Sn (which was inadvertently omitted in the 10,000-year simulation modeling cases) and modified the seepage calculations (Section 6.3.3.1.3[a]).</td>
</tr>
<tr>
<td>P3.</td>
<td>Conservative treatment of WP damage from seismic events following the first breach due to nominal corrosion processes.</td>
<td>Significant between 200,000 and 300,000 years</td>
<td>Yes – Modified seismic damage submodel to remove conservatism (Section 6.6.1.3[a]).</td>
</tr>
<tr>
<td>P4.</td>
<td>WP outer barrier failure flag is triggered when the inside-out corrosion of the WP is initiated in the Seismic GM Modeling Case, which could be earlier than the actual breach time.</td>
<td>Negligible</td>
<td>Yes – Corrected model implementation to more accurately match breach time.</td>
</tr>
<tr>
<td>P5.</td>
<td>In-package chemistry applied in the invert after the DS is failed without considering flow through the WP.</td>
<td>Negligible</td>
<td>Yes – Corrected model implementation to include flow through the WP.</td>
</tr>
<tr>
<td>P7.</td>
<td>Nominal crack failure opening area incorrectly calculated once the elapsed time is greater than the seismic damage time.</td>
<td>Negligible</td>
<td>Yes – Corrected model implementation.</td>
</tr>
<tr>
<td>P8.</td>
<td>Degradation processes inside the WP could start before the breach from an igneous event under certain aleatory configuration of specified igneous event times.</td>
<td>Negligible</td>
<td>Yes – Corrected model implementation.</td>
</tr>
<tr>
<td>P9.</td>
<td>Threshold rubble volume (per drift length) that is used for determining when the non-lithophysal drifts undergo collapse is incorrect. It is currently using the value of 5 m$^3$/m while the correct value is 0.5 m$^3$/m.</td>
<td>Negligible</td>
<td>Yes – Corrected value to 0.5 m$^3$/m.</td>
</tr>
<tr>
<td>P11.</td>
<td>The uncertainty associated with fluoride concentration in calculating the uranium solubility for the CSNF WPs is incorrectly calculated in the Igneous Intrusion Modeling Case.</td>
<td>Negligible</td>
<td>Yes – Corrected model implementation.</td>
</tr>
<tr>
<td>P12.</td>
<td>The ionic strength for the HLW glass domain for conditions where there is flow through the WP always chooses the ionic strength determined for flowing conditions.</td>
<td>Negligible</td>
<td>Yes – Corrected model implementation to select ionic strength based on flow conditions.</td>
</tr>
<tr>
<td>P13.</td>
<td>The average WP length seepage abstraction uses an average WP length of 5.0 m. However, the average length of WPs should be 5.6 m.</td>
<td>Small ($\leq$12%)</td>
<td>No – Small impact ($\leq$12%).</td>
</tr>
<tr>
<td>P14.</td>
<td>Evaluate the mean annual dose from the Igneous Intrusion and Volcanic Eruption Modeling Cases with the probability of the igneous event set to $10^{-7}$ per year. Note that this is purely a sensitivity analysis and not due to any error in the implementation.</td>
<td>None</td>
<td>NA</td>
</tr>
<tr>
<td>P15.</td>
<td>The distribution for longitudinal dispersivity that is sampled produces unrealistically large values in the 1-D SZ flow and transport model.</td>
<td>Small ($&lt;$30%)</td>
<td>Yes – Changed the longitudinal dispersivity (Section 6.3.10[a]).</td>
</tr>
<tr>
<td>Issue No.</td>
<td>Issue Description</td>
<td>Anticipated Impact</td>
<td>Addressed in v5.005</td>
</tr>
<tr>
<td>----------</td>
<td>-----------------------------------------------------------------------------------</td>
<td>--------------------</td>
<td>---------------------</td>
</tr>
<tr>
<td>P16.</td>
<td>The HLW glass degradation rate calculation for the Igneous Intrusion Modeling Case uses the degradation model that was developed for nominal conditions instead of applying an instantaneous degradation</td>
<td>Negligible</td>
<td>Yes – corrected model implementation to include instantaneous degradation for the Igneous Intrusion Modeling Case.</td>
</tr>
<tr>
<td>P17.</td>
<td>The seepage flux in the lithophysal zones following the drift collapse may be under predicted in some realizations due to an error in estimating the bounding values.</td>
<td>Small (~20%)</td>
<td>Yes – corrected model implementation to include the degraded drift diameter of 11 m for estimating bounding values following drift collapse.</td>
</tr>
<tr>
<td>P18.</td>
<td>Minimum iron oxyhydroxide colloid concentration is being applied even under stable conditions due to error in calculating the ionic strength threshold for colloid stability calculations.</td>
<td>Negligible</td>
<td>Yes – corrected model implementation.</td>
</tr>
<tr>
<td>P19.</td>
<td>In the Igneous Intrusion Modeling Case, the number of WPs assigned for computing the DSNF mass in the non-dripping environments are not correctly calculated following the igneous event.</td>
<td>Small (&lt;6%)</td>
<td>Yes – corrected model implementation.</td>
</tr>
<tr>
<td>P20.</td>
<td>GoldSim software error where incorrect masses could be calculated by the Source and Pipe elements (special GoldSim elements) when decay chains have feedback loops.</td>
<td>Small (&lt;5%)</td>
<td>Yes – No impact.</td>
</tr>
<tr>
<td>P21.</td>
<td>Delay in transport for some radionuclides through the fault zones in the UZ transport model.</td>
<td>Small (&lt;5%)</td>
<td>No. Small (&lt;5%)</td>
</tr>
<tr>
<td>P22.</td>
<td>Other minor implementation errors that have been discovered since running the compliance case are grouped and addressed (Table P-6).</td>
<td>Negligible</td>
<td>See Table P-6[a]</td>
</tr>
<tr>
<td>P23.</td>
<td>Several suggested changes to the model file structure are tracked in a model status log.</td>
<td>None</td>
<td>Yes.</td>
</tr>
</tbody>
</table>
Figure P-20[a]. Expected Annual Dose versus Average Seepage Fraction for the Nominal Modeling Case for 1,000,000 Years after Repository Closure

Source: Output DTN: MO0710ADTSPAWO.000 [DIRS 183752].
Figure P-21[a]. Expected Annual Dose versus Average Seepage Fraction for the Seismic Ground Motion Modeling Case for (a) 10,000 Years and (b) 1,000,000 Years after Repository Closure