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YUCCA MOUNTAIN - REQUEST FOR ADDITIONAL INFORMATION - SAFETY EVALUATION REPORT, VOLUME 3 - POSTCLOSURE CHAPTER 2.2.1.4.1 - COMPLIANCE WITH THE POSTCLOSURE INDIVIDUAL PROTECTION STANDARD, 2ND SET - (DEPARTMENT OF ENERGY'S SAFETY ANALYSIS REPORT SECTION 2.4.2)

Reference: Ltr, Sulima to Williams, dtd 9/29/2009, "Yucca Mountain – Request for Additional Information – Safety Evaluation Report, Volume 3 – Postclosure Chapter 2.2.1.4.1 – Compliance with Postclosure Individual Protection Standard, 2nd Set – (Department of Energy's Safety Analysis Report Section 2.4.2)"

The purpose of this letter is to transmit the U.S. Department of Energy's (DOE) responses to the Requests for Additional Information (RAI) identified in the above-referenced letter. Each RAI response is provided as a separate enclosure (Enclosures 1 through 3).

Enclosures 4 and 5 of the letter are optical storage media (OSM) containing GoldSim model files and supporting documentation for the 1,000,000-year seismic ground motion and the igneous intrusion modeling cases, respectively, as requested in RAI Number 3. Each disk includes a listing of the electronic files on each DVD, in PDF format. The electronic files will be made available to the public upon request.

Most of the DOE references cited in the RAI responses have previously been provided with the License Application (LA) and the LA update. One DOE reference that is cited in RAI Number 1, has not been previously provided to the Nuclear Regulatory Commission, and is included with this submittal as Enclosure 6.

There are no commitments in the enclosed RAI responses. If you have any questions regarding this letter, please contact me at (202) 586-9620, or by email to jeff.williams@rw.doe.gov.

Steven E Gomberg (for)

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NMSS25

Enclosures (6):

1. Response to RAI Volume 3, Chapter 2.2.1.4.1, Set 2, Number 1
2. Response to RAI Volume 3, Chapter 2.2.1.4.1, Set 2, Number 2
3. Response to RAI Volume 3, Chapter 2.2.1.4.1, Set 2, Number 3
4. Optical Storage Media – DVD containing GoldSim model file and supporting documentation (including Navigational_Aid_For_Results.pdf) for the 1,000,000-year seismic ground motion modeling case, RTN00573_SMM_001.gsm, discussed in the response to RAI Number 3.
5. Optical Storage Media – DVD containing GoldSim model file and supporting documentation (including Navigational_Aid_For_Results.pdf) for the 1,000,000-year igneous intrusion modeling case, RTN00573_IGM_001.gsm, discussed in the response to RAI Number 3.
6. DOE (U.S. Department of Energy) 2007. *Design Document for: EXDOC_LA Version 2.0.* Document ID: 11193-DD-2.0-01. Las Vegas, Nevada: U. S. Department of Energy, Office of Repository Development. ACC: LLR.20091014.0076.

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RAI Volume 3, Chapter 2.2.1.4.1, Second Set, Number 1:

RAI: Provide a detailed description of the numerical integration method used to evaluate the expected dose over the waste package damage area (faulting and seismic model cases). In particular, describe how the contribution to the expected dose from the zero waste package damage area to the first discrete value (e.g., 1/3 in the faulting model case) of the damage area was accounted for. It is not apparent that the contribution from the initial portion of the damage area is included in the integration result within the EXDOC implementation.

Basis: The numerical value of the expected dose over the waste package damage area may vary depending on the numerical integration approach and the number of integration points. As an illustration, Appendix J of SNL (2008) provides a description of the computation of the expected dose for the fault displacement model case. Three realizations with discrete fractions of the waste package damage area (1/3, 2/3, and 1) were used to compute the expected dose over the damage area. SAR Section 2.4.2.2.2 described the effect of simultaneously increasing the number of fault events (from 6 to 12) and the number of waste package damage areas (from 3 to 5) on the expected dose for 5 realizations (SAR Figure 2.4-61), and estimated an increase in the expected dose by 30 percent for all the 5 realizations considered (SAR p. 2.4-88). If the dose were independent of the damage area, the segment ranging from 0 to 1/3 fraction of the damage area would contribute 1/3 of the expected dose. The reported increase by 30% (SAR p. 2.4-88) could be explained as the contribution from this [0, 1/3] segment, implying that this segment was potentially disregarded in the numerical integration algorithm.

In general, a detailed description is needed of the numerical integration method to compute expected values over the damage area for all other model cases that consider discrete values of this variable. In particular, discuss the treatment of the first damage area element ranging from 0 to the first discrete value.

1. RESPONSE

The numerical methods used to compute the expected values of dose to the reasonably maximally exposed individual (RMEI) for the seismic ground motion and seismic fault displacement modeling cases are described below. In particular, the response explains the numerical integration of annual dose over the uncertain damaged area, and how damaged areas ranging from zero to the first discrete value are accounted for in the integral. Finally, further evidence is provided to show that the expectation of dose over the uncertain damaged area is computed with sufficient accuracy in the seismic fault displacement modeling case.

1.1 DESCRIPTION OF NUMERICAL METHODS FOR CALCULATING EXPECTED DOSE

For the seismic ground motion modeling case for 10,000 years postclosure, and seismic fault displacement modeling case for either 10,000 years or 1,000,000 years postclosure, the calculation of the expected (expectation over aleatory uncertainty) dose to the RMEI involves numerical integration, using a quadrature method, over the uncertain damaged area on damaged waste packages. In all other modeling cases, either the damage to waste packages is not uncertain (i.e., in the early failure and igneous modeling cases) or the expected value is computed using a simple Monte Carlo method (i.e., in the nominal modeling case and the seismic ground motion modeling case for 1,000,000 years postclosure).

1.1.1 Seismic Ground Motion Modeling Case for 10,000 Years PostClosure

As described in SAR Section 2.4.2.1.5.4 (Equation 2.4-26), for each realization $\mathbf{e}_i$ of epistemically uncertain parameters, the expected annual dose $\bar{D}_{SG}(\tau|\mathbf{e}_i)$ at time τ for $0 \le \tau \le 10{,}000\,\text{yr}$ is calculated by:

$$\begin{aligned}\bar{D}_{SG}(\tau|\mathbf{e}_i) = &\int_0^\tau \left(\lambda_1(\mathbf{e}_i)\exp(-\lambda_1(\mathbf{e}_i)t)\left(\int_0^D D_{SG}(\tau|[1,t,A],\mathbf{e}_i)\, d_{A1}(A|\mathbf{e}_i)\, dA \right)\right) dt \\ &+ \int_0^\tau \left(\lambda_1(\mathbf{e}_i)\exp(-\lambda_1(\mathbf{e}_i)t)\left(\int_t^\tau \int_0^D D_{SG}(\tau|[1,s,B],\mathbf{e}_i)\, d_{A2}(B|\mathbf{e}_i)\, dB\, \lambda_2(\mathbf{e}_i)\, ds \right)\right) dt \end{aligned} \quad \text{(Eq. 1)}$$

where

$\lambda_1(\mathbf{e}_i)$	is the frequency of seismic ground motion events that cause stress corrosion cracking (SCC) damage to codisposal waste packages with intact internals
$\lambda_2(\mathbf{e}_i)$	is the frequency of seismic ground motion events that cause SCC damage to codisposal waste packages with degraded internals
D	is the surface area of a codisposal waste package
$d_{A1}(A\|\mathbf{e}_i)$	is the density function for damaged area A occurring on codisposal waste packages with intact internals, given that a seismic event that causes damage occurs

$d_{A2}(B\|\mathbf{e}_i)$	is the density function for damaged area B occurring on codisposal waste packages with degraded internals, given that a seismic event that causes damage occurs
$D_{SG}(\tau\|[1,t,A],\mathbf{e}_i)$	is the annual dose at time τ resulting from a seismic ground motion event occurring at time t that causes damaged area equal to A.

The quantity $D_{SG}(\tau|[1,t,A],\mathbf{e}_i)$ is computed by the GoldSim component of the TSPA-LA model for specified values of t and A, as listed in *Total System Performance Assessment Model/Analysis for the License Application* (i.e., TSPA-LA Model report, SNL 2008, Table 6.6-3[a]). The integral in Equation 1 is numerically evaluated by the EXDOC_LA component of the TSPA-LA model, which employs quadrature techniques to integrate over damaged areas A and B and time, t. The technique is illustrated schematically in SAR Figure 2.4-8.

As outlined in the TSPA-LA Model report (SNL 2008, Equations J8.3-8 to J8.3-17), numerical evaluation of Equation 1 involves three steps:

1. Calculation of expectation of annual dose over uncertain damaged area, for each specified event time t, by evaluation of $I_1(\tau|t,\mathbf{e}_i)=\int_0^D D_{SG}(\tau|[1,t,A],\mathbf{e}_{Mi})d_{A1}(A|\mathbf{e}_i)dA$ and $I_2(\tau|t,\mathbf{e}_i)=\int_0^D D_{SG}(\tau|[1,t,B],\mathbf{e}_{Mi})d_{A2}(B|\mathbf{e}_i)dB$ to obtain the time histories of the expectation of dose to the RMEI over uncertain damaged area
2. Construction of additional time histories, by interpolation or extrapolation, for event times other than the specified event times
3. Integration over the uncertain time of events to obtain the expected value of dose to the RMEI.

Step 1: Expectation over uncertain damaged area

A set of specified event times $t_1 < t_2 < \ldots < t_{nT}$ are selected that subdivide the interval [0, 20,000]. Also, a set of values $\{A_k\}, k=1,nA$ for damaged area A are specified. Values for $t_1 < t_2 < \ldots < t_n$ and $\{A_k\}, k=1,nA$ are given in the TSPA-LA Model report (SNL 2008, Table 6.6-3[a]). For each combination t_j and A_k, $j=1,\ldots,nT$ and $k=1,\ldots,nA$, $D_{SG}(\tau|[1,t_j,A_k],\mathbf{e}_i)$ is computed by the GoldSim component. When there is no damaged area present, there can be no annual dose to the RMEI; therefore, $D_{SG}(\tau|[1,t_j,0],\mathbf{e}_i)=0$. Additionally, a maximum fractional damaged area $A_{nA+1}=0.005$ is specified; this maximum area exceeds the 99.99th percentile of the cumulative distribution function (CDF) for fractional damaged area caused by a seismic ground motion event, for every epistemic sample element, $\mathbf{e}_i$, and for either intact or degraded waste package internals. Annual dose at this maximum damaged area $D_{SG}\left(\tau \middle| \left[1, t_j, A_{nA+1}\right], \mathbf{e}_i\right)$ was not computed using the GoldSim component; rather, $D_{SG}\left(\tau \middle| \left[1, t_j, A_{nA+1}\right], \mathbf{e}_i\right)$ was estimated by linear extrapolation using $D_{SG}\left(\tau \middle| \left[1, t_j, 0\right], \mathbf{e}_i\right) = 0$ and $D_{SG}\left(\tau \middle| \left[1, t_j, A_{nA}\right], \mathbf{e}_i\right)$ as the endpoints, that is:

$$D_{SG}\left(\tau \middle| \left[1, t_j, A_{nA+1}\right], \mathbf{e}_i\right) = \frac{A_{nA+1}}{A_{nA}} D_{SG}\left(\tau \middle| \left[1, t_j, A_{nA}\right], \mathbf{e}_i\right) \qquad \text{(Eq. 2)}$$

This extrapolation overestimates the quantity $D_{SG}\left(\tau \middle| \left[1, t_j, A_{nA+1}\right], \mathbf{e}_i\right)$ because, as illustrated in the TSPA-LA Model report (SNL 2008, Figure 7.3.2-12), annual dose is not proportional to damaged area for sufficiently large damaged areas. This conservative extrapolation approach has been implemented for computational efficiency, and has a negligible effect on the estimation of $I_1\left(\tau \middle| t_j, \mathbf{e}_i\right)$ and $I_2\left(\tau \middle| t_j, \mathbf{e}_i\right)$ because the range of fractional damaged area involved represents less than 0.01% of the CDF for fractional damaged area.

Numerical evaluation of $I_1\left(\tau \middle| t_j, \mathbf{e}_i\right)$ and $I_2\left(\tau \middle| t_j, \mathbf{e}_i\right)$ is performed using a trapezoid rule; however, direct implementation is numerically inefficient. Using a trapezoid rule, for $A_k \le A \le A_{k+1}$, $D_{SG}\left(\tau \middle| \left[1, t_j, A\right], \mathbf{e}_i\right)$ is estimated by linear interpolation between $D_{SG}\left(\tau \middle| \left[1, t_j, A_k\right], \mathbf{e}_i\right)$ and $D_{SG}\left(\tau \middle| \left[1, t_j, A_{k+1}\right], \mathbf{e}_i\right)$. Values for the CDFs corresponding to the density functions $d_{A1}\left(A \middle| \mathbf{e}_i\right)$ and $d_{A2}\left(A \middle| \mathbf{e}_i\right)$ are calculated separately using MathCAD to evaluate the integral shown in the TSPA-LA Model report (SNL 2008, Equation J8.5.3-3). Using the CDF corresponding to $d_{A1}\left(A \middle| \mathbf{e}_i\right)$ and linear interpolation to estimate $D_{SG}\left(\tau \middle| \left[1, t_j, A\right], \mathbf{e}_i\right)$, $I_1\left(\tau \mid t_j, \mathbf{e}_i\right)$ is computed in EXDOC_LA by (DOE 2007, Equation 5):

$$
\begin{aligned}
I_1\left(\tau \mid t_j, \mathbf{e}_i\right) &= \int_0^D D_{SG}\left(\tau \left| \left[1, t_j, A\right], \mathbf{e}_{Mi}\right.\right) d_{A1}\left(A \middle| \mathbf{e}_i\right) dA \\
&\cong \int_0^{A_{nA+1}} D_{SG}\left(\tau \mid t_j, A, \mathbf{e}_{Mi}\right) d_{A1}\left(A \middle| \mathbf{e}_i\right) dA \\
&= \sum_{i=1}^{nA+1} \int_{A_{i-1}}^{A_i} D_{SG}\left(\tau \mid t_j, A, \mathbf{e}_{Mi}\right) d_{A1}\left(A \middle| \mathbf{e}_i\right) dA \\
&\cong \sum_{i=1}^{nA+1} \int_{A_{i-1}}^{A_i} \left\{ \begin{array}{l} D_{SG}\left(\tau \mid t_j, A_{i-1}, \mathbf{e}_{Mi}\right) + \\ \dfrac{A - A_{i-1}}{A_i - A_{i-1}} \left[D_{SG}\left(\tau \mid t_j, A_i, \mathbf{e}_{Mi}\right) - D_{SG}\left(\tau \mid t_j, A_{i-1}, \mathbf{e}_{Mi}\right) \right] d_{A1}\left(A \middle| \mathbf{e}_i\right) d \end{array} \right\} A \\
&\cong \sum_{i=1}^{nA+1} D_{SG}\left(\tau \mid t_j, A_{i-1}, \mathbf{e}_{Mi}\right) \int_{A_{i-1}}^{A_i} d_{A1}\left(A \middle| \mathbf{e}_i\right) dA \\
&\quad + \sum_{i=1}^{nA+1} \frac{\left[D_{SG}\left(\tau \mid t_j, A_i, \mathbf{e}_{Mi}\right) - D_{SG}\left(\tau \mid t_j, A_{i-1}, \mathbf{e}_{Mi}\right) \right]}{A_i - A_{i-1}} \int_{A_{i-1}}^{A_i} \left(A - A_{i-1}\right) d_{A1}\left(A \middle| \mathbf{e}_i\right) dA \\
&\cong \sum_{i=1}^{nA+1} D_{SG}\left(\tau \mid t_j, A_{i-1}, \mathbf{e}_{Mi}\right) prob_{A1}(A_{i-1} \le A \le A_i) \\
&\quad + \sum_{i=1}^{nA+1} \left\{ \begin{array}{l} \dfrac{\left[D_{SG}\left(\tau \mid t_j, A_i, \mathbf{e}_{Mi}\right) - D_{SG}\left(\tau \mid t_j, A_{i-1}, \mathbf{e}_{Mi}\right) \right]}{A_i - A_{i-1}} \\ \times \left\{ \displaystyle\int_{A_{i-1}}^{A_i} A d_{A1}\left(A \middle| \mathbf{e}_i\right) dA - A_{i-1} prob_{A1}\left(A_{i-1} \le A \le A_i\right) \right\} \end{array} \right\}
\end{aligned} \qquad \text{(Eq. 3)}
$$

The integral remaining on the last line of Equation 3 (i.e., $\int_{A_{i-1}}^{A_i} A d_{A1}\left(A \middle| \mathbf{e}_i\right) dA$) is also evaluated using a trapezoid rule; values of $d_{A1}\left(A \middle| \mathbf{e}_i\right)$ are obtained by numerically differentiating the associated CDF. $I_2\left(\tau \mid t_j, \mathbf{e}_i\right)$ is estimated in the same manner.

Equations J8.3-16 and J8.3-17 and the accompanying discussion in the TSPA-LA Model report (SNL 2008) convey the fact that a quadrature technique is used for these integrals, but the description does not precisely identify the method used (trapezoid rule) nor indicate the use of extrapolation outside the range defined by $\{A_k\}, k = 1, nA$. Information at that level of detail is provided in the *Design Document for: EXDOC_LA Version 2* (DOE 2007).

Step 2: Construction of additional time histories

Having obtained $I_1(\tau \mid t_j, \mathbf{e}_i)$ and $I_2(\tau \mid t_j, \mathbf{e}_i)$ for $t_j \in \{t_1, t_2, \ldots, t_{nT}\}$ as described in Step 1, these quantities are used to construct additional time histories $\hat{I}_1(\tau \mid t, \mathbf{e}_i)$ and $\hat{I}_2(\tau \mid t, \mathbf{e}_i)$ for any event time t, $0 \le t \le 20{,}000$, by interpolation such that the shape of $\hat{I}_1(\tau \mid t, \mathbf{e}_i)$ (i.e., as a function of τ) varies smoothly between $I_1(\tau \mid t_j, \mathbf{e}_i)$ and $I_1(\tau \mid t_{j+1}, \mathbf{e}_i)$ where $t_j \le t \le t_{j+1}$.

For $t_j \le t \le t_{j+1}$ and $\tau \le 20{,}000 \text{ yr} - (t_{j+1} - t)$, $\hat{I}_1(\tau \mid t, \mathbf{e}_i)$ is estimated by (DOE 2007, Section 4.1.5):

$$\hat{I}_1(\tau \mid t, \mathbf{e}_i) = I_1\left(\tau - (t - t_j) \mid t_j, \mathbf{e}_i\right) + \frac{t - t_j}{t_{j+1} - t_j}\left(I_1\left(\tau - (t - t_{j+1}) \mid t_{j+1}, \mathbf{e}_i\right) - I_1\left(\tau - (t - t_j) \mid t_j, \mathbf{e}_i\right)\right) \quad \text{(Eq. 4)}$$

The interpolation method is illustrated in Figure 1 (with notation $t = t_I$, $t_j = t_L$, $t_{j+1} = t_R$, and $\tau = t + \Delta t$); the red curve corresponds to $I_1(\tau \mid t_j, \mathbf{e}_i)$, the blue curve corresponds to $I_1(\tau \mid t_{j+1}, \mathbf{e}_i)$, and the green point is the interpolated value for $I_1(\tau \mid t, \mathbf{e}_i)$. Results of the interpolation are illustrated in the TSPA-LA Model report (SNL 2008, Figures J8.3-3c and J8.3-3d).

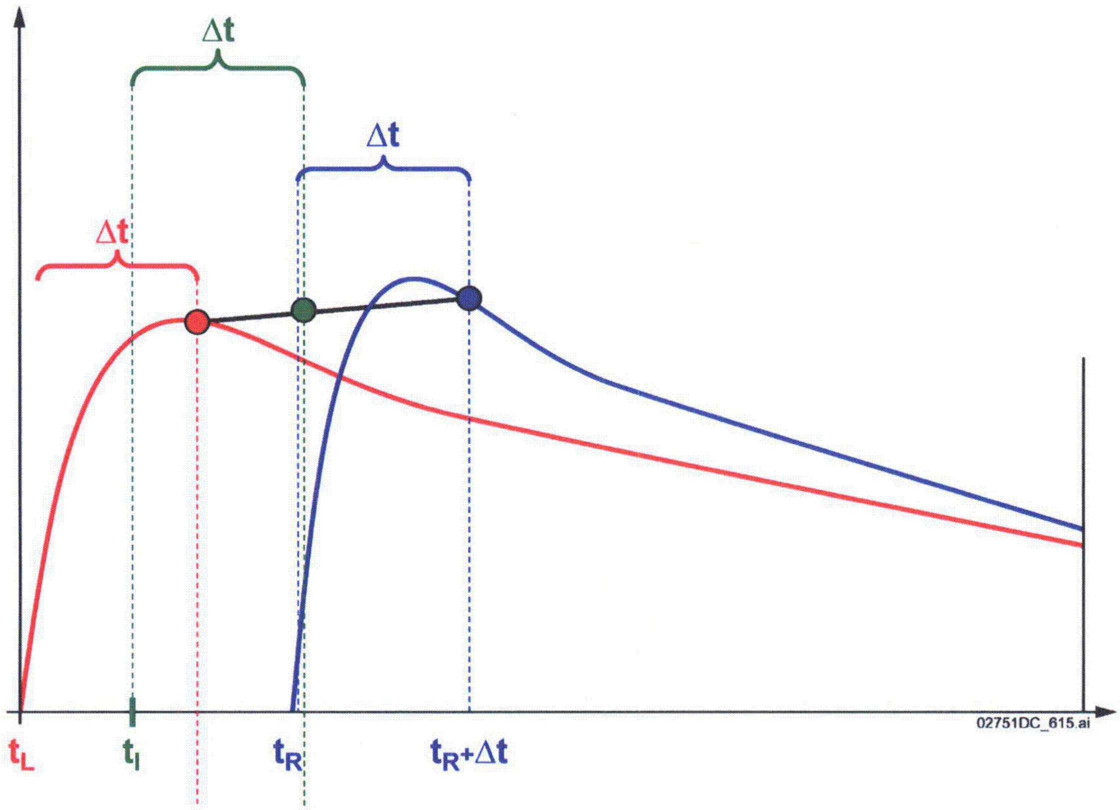


Figure 1. Illustration of Interpolation Method used to Construct Additional Time Histories

For $t_j \le t \le t_{j+1}$ and $\tau > 20{,}000\ \text{yr} - \left(t_{j+1} - t\right)$ (i.e., $t_R + \Delta t$ in Figure 1 is greater than 20,000 years), the time history for the right end point is no longer used, and $\hat{I}_1(\tau \mid t, \mathbf{e}_i)$ is estimated only using the time history for the left end point resulting in the approximation:

$$\hat{I}_1(\tau \mid t, \mathbf{e}_i) = I_1\left(\tau - \left(t - t_j\right) \mid t_j, \mathbf{e}_i\right) \tag{Eq. 5}$$

For $0 \le t < t_1$, $\hat{I}_1(\tau \mid t, \mathbf{e}_i)$ is estimated by shifting $I_1(\tau \mid t_1, \mathbf{e}_i)$ to earlier times, that is, $\hat{I}_1(\tau \mid t, \mathbf{e}_i) = I_1\left(\tau - (t - t_1) \mid t_1, \mathbf{e}_i\right)$. For $t_{nT} \le t$, $\hat{I}_1(\tau \mid t, \mathbf{e}_i)$ is estimated by shifting $I_1(\tau \mid t_{nT}, \mathbf{e}_i)$, that is, $\hat{I}_1(\tau \mid t, \mathbf{e}_i) = I_1\left(\tau - (t - t_{nT}) \mid t_{nT}, \mathbf{e}_i\right)$.

Additional time histories for $\hat{I}_2(\tau \mid t, \mathbf{e}_i)$ are constructed in the same manner.

Step 3: Expectation over uncertain event time

Having constructed additional time histories for $\hat{I}_1(\tau \mid t, \mathbf{e}_i)$ and $\hat{I}_2(\tau \mid t, \mathbf{e}_i)$ for a refined, uniform subdivision of [0, τ], $0 = \hat{t}_0 < \hat{t}_1 < \ldots < \hat{t}_n = \tau$, where $\hat{t}_{j+1} - \hat{t}_j = \Delta\hat{t}$ is a constant, the expectation of annual dose over the uncertain event time is computed by summation, as indicated in the TSPA-LA Model report (SNL 2008, Equation J8.3-13):

$$\bar{D}_{SG}(\tau|\mathbf{e}_i) \cong \sum_{j=1}^{n}\left(\lambda_1(\mathbf{e}_i)\exp\left[-\lambda_1(\mathbf{e}_i)\hat{t}_{j-1}\right]\right)\left(\hat{I}_1(\tau|\hat{t}_j,\mathbf{e}_i) + \sum_{k=j+1}^{n}\left[\hat{I}_2(\tau|\hat{t}_{k-1},\mathbf{e}_i)\right]\lambda_2(\mathbf{e}_i)\,\Delta\hat{t}_k\right)\Delta\hat{t}_j, \quad \text{(Eq. 6)}$$

For the TSPA-LA, for the seismic ground motion modeling case for 20,000 years postclosure, $\Delta t = 10$ yr was used.

1.1.2 Seismic Fault Displacement Modeling Case

As described in SAR Section 2.4.2.1.5.4 (Equation 2.4-28), the expected annual dose due to seismic fault displacement is estimated by:

$$\bar{D}_{SF}(\tau|\mathbf{e}) \cong \sum_{r=1}^{2}\left[\bar{N}_r\lambda_{Fr}/100\right]\left[\int_0^{\tau}\left(\int_0^{D_r} D_{SFr}(\tau\|[1,t,100,A],\mathbf{e})\,d_{Ar}(A)\,dA\right)dt\right] \quad \text{(Eq. 7)}$$

where

λ_{Fr}	is the frequency of fault displacement events that cause damage to waste package of type r
$\bar{N}_r$	is the expected number of waste packages of type r (commercial SNF or codisposal) damaged by one fault displacement event
D_r	is the surface area of a waste package of type r
$d_{Ar}(A)$	is the density function for damaged area on waste packages of type r from a fault displacement, defined over domain $[0, A_r]$, where A_r is the cross-sectional area of a waste package of type r
$D_{SFr}(\tau\|[1,t,100,A],\mathbf{e})$	is the annual dose at time τ resulting from one fault displacement occurring at time t, which damages 100 waste packages of type r, causing area opened equal to A on each waste package of type r.

The expected dose due to seismic fault displacement is the sum of expected dose estimated separately for each type of waste package (commercial SNF or codisposal). For each waste package type, the expected dose calculations are estimating a double integral, over the uncertain time of event and uncertainty in the damaged area.

The numerical procedures for computing expected dose in the seismic fault displacement modeling case are similar to those used in the seismic ground motion modeling case. A set of specified event times $t_1 < t_2 < \ldots < t_{nT}$ are selected that subdivide the interval (either [0, 20,000] or [0, 1,000,000]), and a set of values $\{A_{rk}\}, k = 1,\ldots,nA$ for damaged area A are specified; values for $t_1 < t_2 < \ldots < t_{nT}$ and $\{A_{rk}\}, k = 1,\ldots,nA$ are given in the TSPA-LA Model report (SNL 2008, Table 6.6-3[a]). In the seismic fault displacement modeling case, $nA = 3$, and $\{A_k\} = \left\{\frac{A_r}{3}, \frac{2A_r}{3}, A_r\right\}$, where A_r is the maximum damaged area considered for a waste package of type r (i.e., the cross-sectional area of the waste package). For each combination t_j and A_k, $j = 1,\ldots,n$ and $k = 1,\ldots,nA$, $D_{SFr}\left(\tau \middle| \left[1, t_j, 100, A_k\right], \mathbf{e}_i\right)$ is computed by the GoldSim component. When there is no damaged area present, there can be no annual dose to the RMEI, therefore, $D_{SFr}\left(\tau \middle| \left[1, t_j, 100, 0\right], \mathbf{e}_i\right) = 0$.

The inner integral (over damaged area) in Equation 7 is evaluated first using a trapezoid rule. For $A_k \le A \le A_{k+1}$, $D_{SFr}\left(\tau \middle| \left[1, t_j, 100, A\right], \mathbf{e}_i\right)$ is estimated by linear interpolation between $D_{SFr}\left(\tau \middle| \left[1, t_j, 100, A_k\right], \mathbf{e}_i\right)$ and $D_{SFr}\left(\tau \middle| \left[1, t_j, 100, A_{k+1}\right], \mathbf{e}_i\right)$. A uniform distribution is used for the uncertain damaged area, so $d_{Ar}(A) = \frac{1}{A_r}$. Applying the trapezoid rule:

$$
\begin{aligned}
I_1\left(\tau \mid t_j, \mathbf{e}_i\right) &= \int_0^{D_r} D_{SFr}\left(\tau \middle| \left[1, t_j, 100, A\right], \mathbf{e}_{Mi}\right) d_{Ar}(A)\, dA \\
&= \int_0^{A_r} D_{SFr}\left(\tau \mid \left[1, t_j, 100, A\right], \mathbf{e}_{Mi}\right) \frac{1}{A_r} dA \\
&= \sum_{i=1}^{nA} \int_{A_{i-1}}^{A_i} D_{SFr}\left(\tau \mid \left[1, t_j, 100, A\right], \mathbf{e}_{Mi}\right) \frac{1}{A_r} dA \\
&\cong \sum_{i=1}^{nA} \int_{A_{i-1}}^{A_i} \left\{ \begin{array}{l} D_{SFr}\left(\tau \mid \left[1, t_j, 100, A\right], \mathbf{e}_{Mi}\right) + \\ \frac{A - A_{i-1}}{A_i - A_{i-1}} \left[D_{SFr}\left(\tau \mid \left[1, t_j, 100, A\right], \mathbf{e}_{Mi}\right) - D_{SFr}\left(\tau \mid \left[1, t_j, 100, A\right], \mathbf{e}_{Mi}\right) \right] \frac{1}{A_r} dA \end{array} \right\} \\
&= \sum_{i=1}^{nA} \frac{1}{2A_r} \left[\left(A_i - A_{i-1}\right) \left(D_{SFr}\left(\tau \mid \left[1, t_j, 100, A\right], \mathbf{e}_{Mi}\right) + D_{SFr}\left(\tau \mid \left[1, t_j, 100, A\right], \mathbf{e}_{Mi}\right) \right) \right]
\end{aligned}
$$

(Eq. 8)

Equations J8.6-27 and J8.6-28 and the accompanying discussion in the TSPA-LA Model report (SNL 2008) convey the fact that a quadrature technique is used for the integrals in Equation 8, but the description does not precisely identify the method used. Information at that level of detail is provided in the *Design Document for: EXDOC_LA Version 2* (DOE 2007).

After $I_1\left(\tau \mid t_j, \mathbf{e}_i\right)$ is computed, additional time histories for any event time t are constructed as described in Step 2, and integration over the uncertain time of event is carried out as described in Step 3. For the TSPA-LA, for the seismic fault displacement modeling case for 20,000 years postclosure, $\Delta t = 10$ yr was used; for 1,000,000 years postclosure, $\Delta t = 500$ yr was used. Illustrative results of these steps are provided in the TSPA-LA Model report (SNL 2008, Figure J8.6-3).

1.1.3 Summary of numerical integration technique

As explained in Section 1.1.1 for the seismic ground motion modeling case, and in Section 1.1.2 for the seismic fault displacement modeling case, the calculations for expected dose appropriately include the contribution to expected dose from events that cause damaged area between 0 and the first discrete value of the damaged area used by the GoldSim component of the TSPA-LA model. Annual dose for damaged areas between 0 and the first discrete value are estimated by assuming that annual dose is zero when damaged area is zero, and linearly interpolating between zero and the annual dose corresponding to the first discrete value of the damaged area.

1.2 CONVERGENCE OF NUMERICAL INTEGRATION OVER DAMAGED AREA IN THE SEISMIC FAULT DISPLACEMENT MODELING CASE

The integration of annual dose over the uncertain damaged area is based in part on the assumption that, for damaged area A less than the first discrete value used in the GoldSim part of the TSPA-LA model (i.e., $0 \le A \le A_1$), the annual dose (e.g., $D_{SFr}\left(\tau \middle| \left[1, t_j, 100, A\right], \mathbf{e}_i\right)$) can be estimated by linear interpolation between 0 and $D_{SFr}\left(\tau \middle| \left[1, t_j, 100, A_1\right], \mathbf{e}_i\right)$. If the discretization of damaged area was too coarse, the expectation of annual dose could be underestimated.

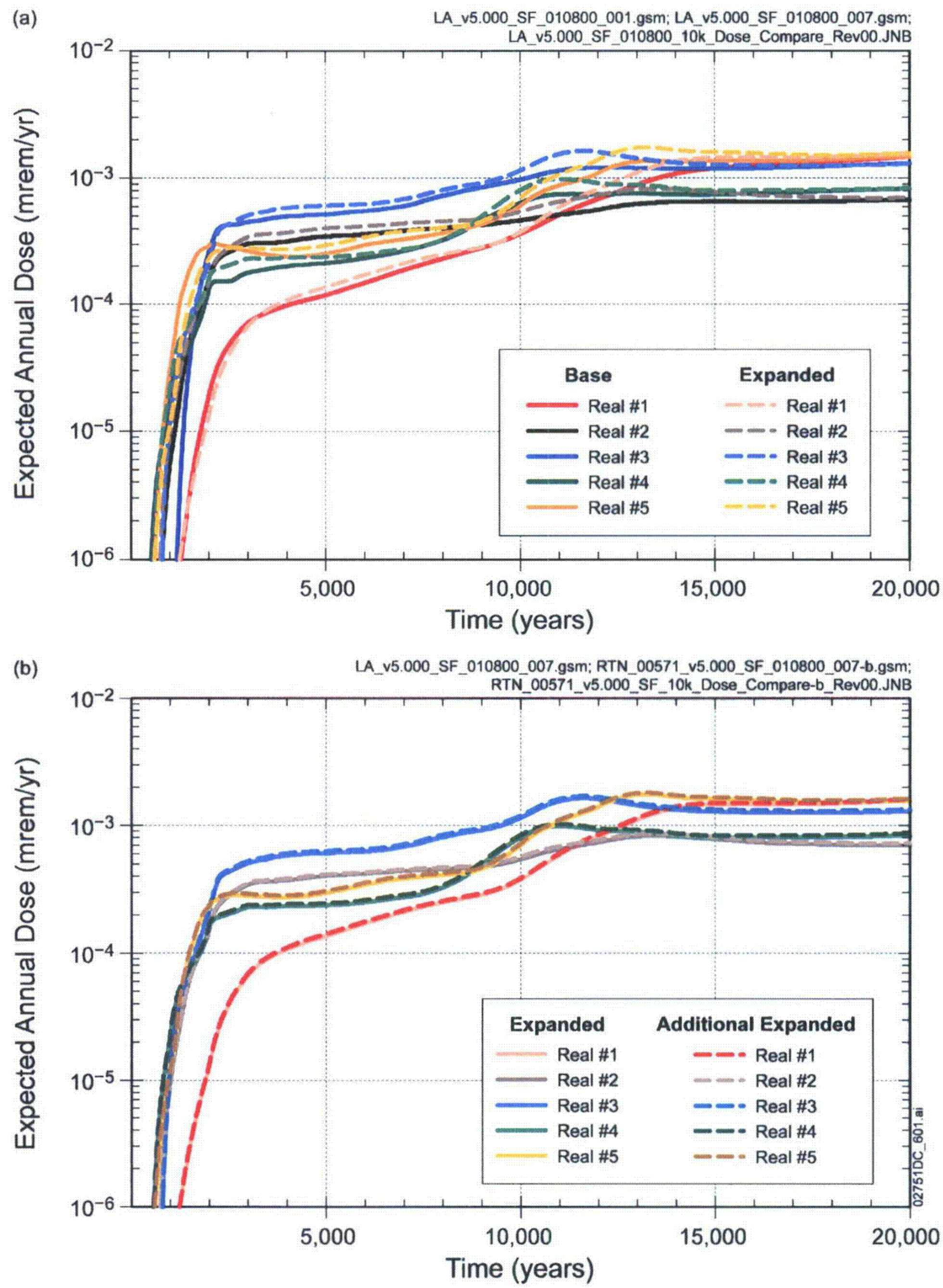
SAR Section 2.4.2.2.2 summarizes an analysis in which the number of discrete damaged areas was increased from three to five, concurrent with an increase in the number of simulated event times from 6 to 12, to demonstrate that the numerical evaluation of expected dose is sufficiently converged. Analysis of the results indicated that the 30% increase in expected dose for the seismic fault displacement modeling case was due to better resolution of the broad increases in annual dose that occurs just after 10,000 years postclosure (SNL 2008, Figures 7.3.2-24 and 7.3.2-25), features which were not well resolved by the original six event times. Because expected dose increased by 30% in the more refined case, a further refinement on event times was performed, increasing the number of event times from 12 to 23. The further refinement showed no additional increase in expected dose when additional event times were considered. Because the seismic fault displacement modeling case is not a significant contributor to total mean annual dose (SAR Figure 2.4-18), the improvement in the accuracy of this modeling case did not justify including the additional event times.

However, the further refinement study summarized in SAR Section 2.4.2.2.2 did not investigate whether expected dose would change if additional damaged areas were considered. Figure 2 compares expected dose for five epistemic sample elements for the seismic fault displacement modeling case between the TSPA-LA base case (six event times and three damaged areas), the expanded case presented in SAR Figure 2.4-61 (twelve event times and five damaged areas), and an additional expanded case using twelve event times and nine damaged areas. Event times and damaged area values for all three cases are listed in Table 1. Figure 2b illustrates that increased refinement in the discretization of damaged area does not produce different estimates of expected dose. Thus, expected dose for the seismic fault displacement modeling case is estimated with sufficient accuracy in the TSPA-LA.

Table 1. Event Times and Damaged Areas Used to Demonstrate Numerical Accuracy of Expected Annual Dose for the Seismic Fault Displacement Modeling Case

	Base Case[a]	**Expanded Case**[b]	**Additional Expanded Case**[c]
Event Times (yrs)	200, 800, 2000, 4000, 8000, 18000	200, 1600, 3200, 4800, 6400, 8000, 9600, 11200, 12800, 14400, 16000, 19200	200, 1600, 3200, 4800, 6400, 8000, 9600, 11200. 12800, 14400, 16000, 19200
Damaged Areas (fraction of cross section area)	1/3, 2/3, 1	1/12, 1/6, 1/3, 2/3, 1	1/192, 1/96, 1/48, 1/24, 1/12, 1/6, 1/3, 2/3, 1

Source: [a, b]) SNL 2008, Table 7.3.2-4; [c]) Values used for results shown in Figure 2b of this RAI response.



Source: (a) SAR Figure 2.4-61.

Figure 2. Expected Annual Dose Over 20,000 Years for Seismic Fault Displacement Modeling Case Considering (a) Additional Specified Event Times and Damaged Areas, and (b) Further Additional Damaged Areas

2. COMMITMENTS TO NRC

None.

3. DESCRIPTION OF PROPOSED LA CHANGE

None.

4. REFERENCES

DOE (U.S. Department of Energy) 2007. *Design Document for: EXDOC_LA Version 2.0.* Document ID: 11193-DD-2.0-01. Las Vegas, Nevada: U. S. Department of Energy, Office of Repository Development. ACC: LLR.20091014.0076.

SNL (Sandia National Laboratories) 2008. *Total System Performance Assessment Model /Analysis for the License Application.* MDL-WIS-PA-000005 REV 00 AD 01. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20080312.0001; LLR.20080414.0037; LLR.20080507.0002; LLR.20080522.0113; DOC.20080724.0005; DOC.20090106.0001[a].

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

RAI Volume 3, Chapter 2.2.1.4.1, Second Set, Number 2:

The documentation for the 10,000 year analysis implies the simulation period needs to be 20,000 years for the numerical interpolation technique to be valid. Describe the numerical interpolation method used to compute dose curves for the one million year analysis (SNL 2008 Appendix J, equations J4.5-2 through J4.5-8), which appears to not rely on a similar numerical interpolation approach (i.e., use of a simulation period of 2 million years to appropriately represent the events for a 1 million year period).

Basis: For the computation of 10,000 year expected doses, individual realizations were computed for times that extend to 20,000 years. The computation of the expected dose requires constitutive realization functions to extend up to twice the period of interest (e.g., 20,000 or two-million years) (SNL 2008, Appendix J). It is not clear if two-million year realizations were used to compute the one-million expected doses. An explanation is needed on the computation of the one-million year expected doses.

1. RESPONSE

Although constitutive realization functions used to estimate expected dose at 10,000 years were computed for times extended to 20,000 years, the methods for estimating expected dose do not require calculation of these functions out to twice the period of interest. The calculations out to 20,000 years were performed to assess whether the trends present at the end of the 10,000-year period continue.

The calculation of expected annual dose for the igneous intrusion, volcanic eruption, seismic ground motion, and seismic fault displacement modeling cases involves integrating over uncertainty in the times at which igneous and seismic events occur. Except for the seismic ground motion modeling case for 1,000,000 years postclosure, numerical integration is carried out using quadrature methods, as summarized in *Total System Performance Assessment Model /Analysis for the License Application* (i.e.; TSPA Model report; SNL 2008, Section 6.1.2.4), and described in more detail in Appendix J of the same document (SNL 2008). In the seismic ground motion modeling case for 1,000,000 years postclosure, the integration is carried out using a Monte Carlo method.

The numerical techniques used in the seismic ground motion modeling case for 10,000 years postclosure, and in the seismic fault displacement modeling cases, are outlined in detail in the response to RAI 3.2.2.1.4.1-2-001. These numerical techniques are implemented in the EXDOC_LA software. Dose curves are computed for a few specified event times using the GoldSim component of the Total System Performance Assessment (TSPA) model; dose curves for many additional event times are constructed either by interpolation or by extrapolation, as described in Step 2 of the algorithm. The same interpolation and extrapolation methods are used to construct additional dose curves for the igneous intrusion and volcanic eruption modeling cases.

In the construction of annual dose by the interpolation and extrapolation method, annual dose (in the igneous intrusion modeling case, or the expectation of annual dose over other aleatory variables such as damaged area in the seismic ground motion, seismic fault displacement, and volcanic eruption modeling cases) is extrapolated beyond those computed with the GoldSim component of the TSPA model in the following two cases:

1. Event time t falls beyond the last specified event time t_{nT}. In this case, annual dose at time τ after the event at time t, $D(\tau|t,\mathbf{e})$, is estimated by shifting the annual dose computed for event time t_{nT} by an amount $(t-t_{nT})$, that is, $D(\tau|t,\mathbf{e}) \cong D(t_{nT}+(\tau-t)|t_{nT},\mathbf{e}) = D(\tau-(t-t_{nT})|t_{nT},\mathbf{e})$.

2. The right end point of the interpolation interval falls beyond the end of the time period under consideration (i.e., beyond 20,000 or 1,000,000 years). In this case, annual dose is approximated as being equal to the dose history which defines the left end point. For example, if the dose history being estimated is $D(\tau\,|\,t,\mathbf{e}_i)$, for $t_{j+1}+(\tau-t)\geq 20{,}000$ yr, annual dose is estimated by $D(\tau\,|\,t,\mathbf{e}_i) \cong D(t_j+(\tau-t)\,|\,t_j,\mathbf{e}_i)$.

For the computation of 10,000-year expected doses, the GoldSim component of the TSPA model was used to calculate annual dose over the time period from closure to 20,000 years postclosure due to events occurring at a few specified times (SNL 2008, Section 6.5.1.2 for igneous intrusion and volcanic eruption event times; Table 6.6-3[a] for seismic ground motion and fault displacement event times). Annual doses due to events occurring at other times were constructed by the interpolation method outlined in Step 2 in the response to RAI 3.2.2.1.4.1-2-001. Because the last two specified event times are 8,000 and 18,000 years postclosure, annual dose prior to 10,000 years, constructed by the interpolation method for any event time, is based only on results calculated with the GoldSim component. In particular, neither Case 1 nor Case 2 occurs.

For the computation of expected doses out to 1,000,000 years in the igneous intrusion, volcanic eruption, and seismic fault displacement modeling cases, the latest two event times for which annual dose is computed using the GoldSim component are 400,000 and 800,000 years postclosure. Annual doses due to events occurring later than 800,000 years postclosure (i.e., described by Case 1) are constructed using the extrapolation method outlined in the response to RAI 3.2.2.1.4.1-2-001. This method constructs dose curves that effectively extend beyond 1,000,000 years postclosure by assuming that the annual dose at time $t+\Delta t$ after an event occurring at time t, denoted here by $D(\tau|t)$, is equal to the annual dose at time $800{,}000+\Delta t$ resulting from an event occurring at 800,000 years postclosure (i.e., $D(t+\Delta t|t) = D(800{,}000+\Delta t|800{,}000)$. Annual doses at times between 600,000 and 1,000,000 years postclosure that follow events occurring between 400,000 and 800,000 years postclosure (i.e., described by Case 2) are estimated as equal to the annual dose at the appropriate time following an event occurring at 400,000 years postclosure. The annual doses following such events are estimated by the annual dose between 400,000 and 800,000 years computed by the GoldSim component following an event at 400,000 years.

These assumptions result in an insignificant overestimate of the expected annual dose from all radionuclides, although the method may overestimate the expected annual dose from a particular radionuclide by a greater amount after 800,000 years, as can be observed in the mean dose curves for ^{99}Tc and ^{79}Se in the igneous intrusion modeling case on SAR Figure 2.4-30b. The overestimation is due to the fact that the approximation method does not account for radioactive decay. The effect of this simplification on total expected dose (summed over radionuclides) is negligible because either the radionuclide of interest has a relatively short half-life compared to the time at which annual dose is estimated and, therefore, is not a major contributor to total dose at late time, or it has a long half-life and thus radioactive decay is not significant for the extrapolated period.

In summary, the computation of expected dose for a period of time $[0, T]$ does not require computation using GoldSim of dose curves extending out to $2T$ years. Rather, when either (i) the last event time simulated with GoldSim falls prior to the end of the period of interest (e.g., at 800,000 years, as is the case for the igneous intrusion modeling case for 1,000,000 years postclosure), or (ii) when the right end point of the interpolation interval falls beyond the end of the time period under consideration, an extrapolation method is used to construct dose curves for times out to the end of the period of interest, and dose curves for events occurring after the last event time simulated with GoldSim, and these constructed dose curves are used to compute the expected dose.

2. COMMITMENTS TO NRC

None.

3. DESCRIPTION OF PROPOSED LA CHANGE

None.

4. REFERENCES

SNL (Sandia National Laboratories) 2008. *Total System Performance Assessment Model /Analysis for the License Application*. MDL-WIS-PA-000005 REV 00 AD 01. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20080312.0001; LLR.20080414.0037; LLR.20080507.0002; LLR.20080522.0113; DOC.20080724.0005; DOC.20090106.0001[a].

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

RAI Volume 3, Chapter 2.2.1.4.1, Second Set, Number 3:

For a single aleatory realization of the seismic ground motion and igneous intrusion modeling cases, provide the electronic files containing the GoldSim results and supporting files for a full set of 300 epistemic samples for the following TSPA intermediate results. The aleatory realizations may be selected to be consistent with the results used in responding to RAI Volume 3, Chapter 2.2.1.4.1, First Set, Number 2.

1. All_Uncert_Results
2. All outputs saved in the following GoldSim containers:
    a. \TSPA_Model\Engineered_System\Engineered_System_Out
    b. \TSPA_Model\Results\Mass_Balance
    c. \TSPA_Model\Results\EBS_Out_Results
    d. \TSPA_Model\Results\UZ_Out_results
    e. \TSPA_Model\Results\SZ_out_results
3. Radionuclide specific biosphere dose conversion factors
4. Radionuclide specific groundwater whole body doses
5. Patch and crack waste package failure fraction
6. Patch and crack failed area
7. Waste package water flow rate
8. Waste form degradation rate
9. Distribution coefficients for radionuclides on stationary corrosion products as computed by the surface complexation model

Basis: Needed for NRC staff review

1. RESPONSE

The Total System Performance Assessment (TSPA) model performs numerous calculations pertaining to the performance of the Yucca Mountain repository. The results for many of the intermediate calculations performed by the TSPA model are not included in the SAR or other supporting documents, but can be recorded and reviewed using the result reporting features of the GoldSim software.

Two GoldSim model files have been run again to save additional result information pertaining to the performance of the Engineered Barrier System (EBS) and the Lower Natural Barrier. Time history and final value results from the 1,000,000-year igneous intrusion modeling case and the 1,000,000-year seismic ground motion modeling case are recorded in the model files enclosed with this response. For each modeling case, 300 realizations of the epistemically uncertain parameters are used with fixed event times (i.e., no aleatory uncertainty). For the 1,000,000-year igneous intrusion modeling case, the igneous intrusion event time is fixed at 100,000 years. For the 1,000,000-year seismic ground motion modeling case, the fixed event sequence is the same as for TSPA model realization 4,641; seismic events simulated in this realization are shown in SAR Figure 2.4-92.

The modeling cases supporting this RAI response apply the same configuration settings that support the response to RAI 3.2.2.1.4.1-002.

1.1 MODEL NAVIGATION SUPPORT

Due to the large quantity of results requested in the RAI, amounting to hundreds of time histories, the sampled values and plotted time histories are provided as saved results within the enclosed model files (see the enclosed DVDs containing GoldSim model files *RTN00573_SMM_001.gsm*, *RTN00573_IGM_001.gsm*, and the readme file *Navigational_Aid_for_Results.pdf*). Changes to the model files that support this RAI response include changes to the configuration settings necessary to perform the specified modeling cases and the addition of result elements to capture requested information from the EBS. Additionally, the descriptive text embedded within each model file has been expanded wherever result histories are saved. In addition, two error corrections are also included in the model files. An error in the weighting factor applied by the result elements that report the seepage rate for the igneous intrusion modeling case was corrected. Previously, the seepage rates outputted from the TSPA model were higher than the applied seepage rates and the results had to be corrected in post-processing. In addition, an error in the result elements for the diffusive release rates from the invert below commercial spent nuclear fuel (SNF) waste packages in the non-seeping environment of percolation subregion 3 was corrected. Previously, these elements reported results for the codisposal waste packages. These error corrections are directly associated with result elements that save intermediate results and do not affect the dose calculations. In addition, previously reported results from the affected elements were corrected prior to reporting the values.

Sections 1.2 to 1.10 provide additional details related to navigating the model files and identifying the intermediate results requested by the RAI. In the supporting documentation, GoldSim element names are identified in bold text and model file pathways are italicized.

New result elements have been added to the TSPA model to capture most of the final value and time history results that are specifically requested by this RAI. The results are reported separately for each percolation subregion in separate containers (e.g., **Additional_EBS_Results_for_PS1**) within the general result container located at the model pathway:

\TSPA_Model\Results\Additional_EBS_Results_for_RAI.

A navigational aid, *Navigational_Aid_for_Results.pdf*, has also been prepared that describes the process of reviewing model results that are saved in a GoldSim model file.

1.2 ALL UNCERTAINTY RESULTS

The sampled values for all of the epistemic parameters applied in the TSPA model are captured by the result element **All_Uncert_Results** located at the model pathway:

\TSPA_Model\Results\Epistemic_Results.

In the TSPA model, values for epistemic parameters are sampled within the **Epistemic_Params** submodel. For some of the model parameters, the sampled values may be subjected to additional correlation within the **EBS_Submodel**. The result element **All_Uncert_Results** captures the values that are applied in the TSPA model, after any correlation is applied.

The uncertainty results associated with the **Aleatory_Params** submodel are not saved within the model file. For the single aleatory event cases, these results do not vary from realization to realization. However, additional result elements have been added to capture the time and peak ground velocity of each seismic ground motion event that occurs in the single aleatory realization 4,641 of the seismic ground motion modeling case. The event times and peak ground velocities are reported by model elements **Seismic_Event_Times** and **Seismic_Event_PGVs** located at the model pathway:

\TSPA_Model\Results\Additional_EBS_Results_for_RAI.

1.3 SAVED CONTAINERS

The time histories and final values for all of the GoldSim elements that are located within the five containers that are specifically identified in the RAI are recorded in the two model files that are provided in this RAI response. Additional text has been embedded within the model files to clarify the quantities that are reported by each element.

1.4 BIOSPHERE DOSE CONVERSION FACTORS

A new result element has been added to the model to capture the epistemic samples for the biosphere dose conversion factors. The results are saved by the GoldSim result element named **RN_BDCFs** that is located at the model pathway:

\TSPA_Model\Results\Additional_EBS_Results_for_RAI.

1.5 RADIONUCLIDE DOSE

The time history results for radionuclide and total dose for individual protection standards can be accessed by viewing the result elements located at the model pathway:

\TSPA_Model\Results\Repeat_Aleatory_Results\RN_Doses.

1.6 WASTE PACKAGE PATCH AND CRACK FAILURE FRACTIONS

New result elements have been added to the TSPA model to capture the final value and time history results for the fraction of waste packages that are damaged by patch failures and crack failures. These new elements for each percolation subregion are added to the general results containers discussed in Section 1.1 (e.g., **Additional_EBS_Results_for_PS1**). Within these containers, separate result elements within the subcontainer **WP_Failure_and_Damage** record the results for each damage mechanism (e.g., patches and cracks), each waste package type, and each percolation subregion. The results for each percolation subregion record three histories, one for each percolation subregion environment (e.g., nonseeping, seeping without localized corrosion, and seeping with localized corrosion). For the two modeling cases presented in this RAI response, the damage to the waste packages does not vary by percolation subregion environment and the histories reported for the different percolation subregion environments are the same. However, for these two modeling cases, the seeping with localized corrosion environment has no waste packages.

The time histories for the fraction of commercial SNF and codisposal waste packages in each percolation subregion environment that are failed by nominal corrosion processes and/or a disruptive event are recorded by GoldSim elements **f_CSNF_WPs_Failed_PS** and **f_CDSP_WPs_Failed_PS**, respectively.

The time histories for the fraction of commercial SNF and codisposal waste packages in each percolation subregion environment that are failed by general corrosion patches are recorded by GoldSim elements **f_CSNF_WPs_Pat_Breach_PS** and **f_CDSP_WPs_Pat_Breach_PS**, respectively. For the igneous intrusion modeling case, these results do not consider the damage from the igneous intrusion event. For the seismic ground motion modeling case, these results do not include the fraction of waste packages that are damaged by seismic rupture or puncture events. For the two disruptive event scenarios, the fractions of waste packages that have patch damage caused by the events are recorded by the elements **f_CSNF_WPs_DE_Pat_PS** and **f_CDSP_WPs_DE_Pat_PS**.

The time histories for the fraction of commercial SNF and codisposal waste packages in each percolation subregion environment that are failed by stress corrosion cracks in the closure lid weld region are recorded by GoldSim elements **f_CSNF_WPs_Crk_Breach_PS** and **f_CDSP_WPs_Crk_Breach_PS**, respectively. For the igneous intrusion modeling case, these results do not consider the damage from the igneous intrusion event. For the seismic ground motion modeling case, these results do not include the fraction of waste packages that are damaged by seismic events. For the two disruptive event scenarios, the fractions of waste packages that have crack damage caused by the events are recorded by the elements **f_CSNF_WPs_DE_Crk_PS** and **f_CDSP_WPs_DE_Crk_PS**.

1.7 WASTE PACKAGE PATCH AND CRACK DAMAGE AREA

Result elements recording the waste package damage areas are added to the same containers holding the waste package failure fractions discussed in Section 1.6. The time histories for the average patch area on all failed commercial SNF and codisposal waste packages in each percolation subregion environment are recorded by GoldSim elements **Patch_Area_CSNF_PS** and **Patch_Area_CDSP_PS**, respectively. Result elements **Patch_Area_CSNF_PS_Pat_Only** and **Patch_Area_CDSP_PS_Pat_Only** report the average patch area for only those waste packages that have patch damage. **Crack_Area_CSNF_PS**, **Crack_Area_CDSP_PS**, **Crack_Area_CSNF_PS_Crk_Only**, and **Crack_Area_CDSP_PS_Crk_Only** report the similar results for waste package crack damage. For diffusive releases from the waste package, the diffusive area is equated to the sum of the patch area and crack area, but is limited to the total surface area of the waste package. For the igneous intrusion modeling case, the waste package outer barrier is completely damaged by patches and the surface area (mm^2) damaged by cracks is set to zero to ensure that the diffusive area does not exceed the surface area of the waste package.

1.8 WASTE PACKAGE WATER FLOW RATE

New result elements have been added to the TSPA model to capture the final value and time history results for the water flow rate through failed waste packages. Within the percolation subregion specific containers of the general results container discussed in Section 1.1 (e.g., **Additional_EBS_Results_for_PS1**), separate result elements record the results for each waste package type. The flow rate through failed commercial SNF and codisposal waste packages is reported by model elements **QFlux_WP_CSNF_PS** and **QFlux_WP_CDSP_PS**, respectively. Each result element records three histories, one for each percolation subregion environment (e.g., nonseeping, seeping without localized corrosion, and seeping with localized corrosion).

1.9 WASTE FORM DEGRADATION RATES

New result elements have been added to the TSPA model to capture the final value and time history results for the waste form degradation rates inside failed commercial SNF and codisposal waste packages. Within the percolation subregion specific containers of the general results container discussed in Section 1.1 (e.g., **Additional_EBS_Results_for_PS1**), separate result elements record the results for each waste package type. The waste form degradation rate for the commercial SNF is reported by model element **CSNF_WF_Deg_Rate_PS**. Similarly, the degradation rate of the high-level waste glass inside codisposal waste packages is reported by the model element **HLW_WF_Deg_Rate_PS**. The waste form degradation rate for DOE SNF inside failed codisposal waste packages is not reported because the DOE SNF waste form degrades instantly once the waste package fails. Each result element records three histories, one for each percolation subregion environment (e.g., nonseeping, seeping without localized corrosion, and seeping with localized corrosion).

The waste from degradation rates reported by the added result elements are the calculated rates at the prevailing temperature, relative humidity, and chemical conditions (e.g., pH, PCO_2, and PO_2) in the waste form domain at each time step. For reporting purposes, the degradation rates have been set to zero/yr for times prior to the first waste package breach. After this time, the degradation rates are calculated and reported, whether or not there is any waste form remaining to degrade.

1.10 SURFACE COMPLEXATION MODEL DISTRIBUTION COEFFICEIENTS

New result elements have been added to the TSPA model to capture the final value and time history results for the radionuclide specific corrosion product distribution coefficients calculated using the surface complexation model. Distribution coefficient values are reported for americium, plutonium, neptunium, uranium, and thorium partitioning onto corrosion products in the corrosion products domain. Within the percolation subregion specific containers of the general results container discussed in Section 1.1 (e.g., **Additional_EBS_Results_for_PS1**), separate result elements record the results for each waste package type and percolation subregion environment (e.g., nonseeping and seeping without localized corrosion). In the modeling cases considered, there are no waste packages assigned to the seeping with localized corrosion environment; therefore, result elements have not been added to report the distribution coefficients for this environment. For commercial SNF waste packages in the nonseeping and seeping without localized corrosion environments, the distribution coefficients for americium, plutonium, neptunium, uranium, and thorium partitioning onto corrosion products in the corrosion products domain are reported by model elements **CP_Kd_CSNF_ND_PS** and **CP_Kd_CSNF_D_PS**, respectively. Similar results are reported for codisposal waste packages by model elements **CP_Kd_CDSP_ND_PS** and **CP_Kd_CDSP_D_PS**.

2. COMMITMENTS TO NRC

None.

3. DESCRIPTION OF PROPOSED LA CHANGE

None.

4. LIST OF ATTACHMENTS

One DVD with the GoldSim model file and supporting documentation (including Navigational_Aid_For_Results.pdf) for the 1,000,000-year seismic ground motion modeling case, RTN00573_SMM_001.gsm, discussed in the RAI response. This DVD is included as enclosure 4.

One double layer DVD with the GoldSim model file and supporting documentation (including Navigational_Aid_For_Results.pdf) for the 1,000,000-year igneous intrusion modeling case, RTN00573_IGM_001.gsm, discussed in the RAI response. This DVD is included as enclosure 5.