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Scientific Analysis/Calculation Error Resolution Document

Complete only applicable items.

QA: QA
Page 1 of 56

1. Document Number: ANL-WIS-MD-000027	2. Revision/Addendum: REV 00	3. ERD: 06

4. Title: *Features, Events, and Processes for the Total System Performance Assessment: Analyses*	5. No. of Pages Attached: 34

6. Description of and Justification for Change (Identify affected pages, applicable CRs and TBVs):

I. Background Information Summary:

This Error Resolution Document (ERD) is provided to update *Features, Events, and Processes for the Total System Performance Assessment: Analyses*, Rev 00 to correct issues identified in the following Condition Reports (CRs):

13392, *Creep FEP Analysis Temperature*
13416, *CDSP void space calculation in FEP*
13519, *Clarification needed for FEPs AMR*
13666, *Reference error in ANL-WIS-MD-000027 REV 00*
13735, *Improve clarity in FEP report regarding performance of Waste Package Pallet*
13746, *FEP "Water Table Rise Affects UZ" does not address repository flooding*

This ERD also addresses impacts from *Screening Analysis of Criticality Features, Events, and Processes*, Rev 00 ERD 05.

The minor corrections presented here do not change the screening decisions and therefore have no impact to the overall conclusion of the report.

II. Inputs and/or Software:

One new input source is used in this ERD. DTN: SN0702PAIPC1CA.001 [DIRS 186224] is used to satisfy CR 13416. No new software is used in this ERD.

III. Analysis and Results

The following changes to the document are presented in this section by CR number with a summary of the required changes. Adobe Acrobat representations of each of the changed pages are included as an attachment to this ERD.

(continued on next page)

	Printed Name	Signature	Date
7. Checker	Joon Lee		12/17/09
8. QCS/QA Reviewer	Peter Persoff	Peter Persoff	12/17/2009
9. Originator	Geoff Freeze / Roger Henning	Geoff Freeze	12/17/09
10. Responsible Manager	Jerry A. McNeish	Jerry A McNeish	12·17·09.

To satisfy CR 13392:

1. FEP 2.1.07.05.0B, p. 6-565, Screening Justification, second paragraph

   should be changed to:

   "Plastic deformation and mechanical damage of the drip shield are expected to be enhanced at elevated temperatures due to the combined effect of thermal and mechanical stresses. The hottest waste package temperature in an open drift remains below 150°C for over 98% of the 10,000 years following closure of the repository (SNL 2008 [DIRS 184433], Figure 6.3-76[a]). Due to greater distance of the drip shield from the heat source (i.e., the waste form) than the waste package, surface temperatures of the drip shield will be lower than those for the waste packages. For the waste package surface to exceed 300°C, a seismic event of sufficient magnitude must occur within approximately 90 years after closure, result in a drift collapse, and affect a waste package with an unfavorable combination of a high thermal output surrounded by a low conductivity rubble (SNL 2008 [DIRS 179962], Section 6.5.1). However, even if such a scenario were to take place, the hottest waste package temperature will still be below 150°C for approximately 94% of the 10,000 years following closure of the repository (SNL 2008 [DIRS 184433], Figure 6.3-82[a]). Analyses have shown that the mean probability of these conditions occurring is about one in 10,000 within the first 10,000 years after closure (SNL 2008 [DIRS 179962], Section 6.5.1). Therefore, a reasonably bounding drip shield exposure temperature in the repository is 150°C and is used in the analysis of creep of metallic materials in the drip shield."

2. Table 2.1.07.05.0B-1, p. 6-567, row 2, "Description", the misspelled word - Anaysis

   should be changed to:

   Analysis

3. Table 2.1.07.05.0B-1, p. 6-567, row 3, "Description"

   should be changed to:

   "Hottest waste package temperature in an open drift is below 150°C for over 98% of the 10,000 years following closure." (The DIRS report will be updated accordingly.)

4. Table 2.1.07.05.0B-1, p. 6-567

   add the following Source and Description to the entry for DIRS 184433:

   Figure 6.3-82[a], Hottest waste package temperature in a collapsed drift is below 150°C for approximately 94% of the 10,000 years following closure. (The DIRS report will be updated accordingly.)

To satisfy CR 13416:

1. FEP 2.1.02.08.0A, p. 6-337,

   "The void volume of the codisposal waste packages containing two MCOs packages is 7,400 liters (DTN: SN0702PAIPC1CA.001 [DIRS 180451], spreadsheet: *CDSP-2MCO Cell 1.xls*, sheet: "WP Cell 1 Moles & Surf Areas," cell: G11). Given that the mole fraction of oxygen in air is 0.20946 (Weast 1984 [DIRS 106170], p. F-162), the moles of oxygen ingress into a breached waste package as a result of barometric pumping can be calculated as: 7,400 liters × 0.02 × 365 days per year/22.4 liters per mole × 0.20946 (oxygen mole fraction in air) = 505 moles oxygen per year."

should be changed to: (highlight indicates changed values)

"The void volume of the codisposal waste packages containing two MCOs packages is 5,700 liters (DTN: SN0702PAIPC1CA.001 [DIRS 186224], spreadsheet: *CDSP-2MCO Cell 1.xls*, sheet: "WP Cell 1 Moles & Surf Areas," cell: G12). Given that the mole fraction of oxygen in air is 0.20946 (Weast 1984 [DIRS 106170], p. F-162), the moles of oxygen ingress into a breached waste package as a result of barometric pumping can be calculated as: 5,700 liters × 0.02 × 365 days per year/22.4 liters per mole × 0.20946 (oxygen mole fraction in air) = 389 moles oxygen per year."

2. FEP 2.1.02.08.0A Table 2.1.02.08.0A-1 Direct Inputs (Continued) on page 6-340, row 1:

Input	Source	Description
DTN: SN0702PAIPC1CA.001. In-Package Chemistry Calculations and Abstractions. [DIRS 180451]	file: *CDSP-2MCO Cell 1.xls*, worksheet: "WP Cell 1 Moles & Surf Areas," cell: G11	The void volume of the codisposal waste packages containing two MCOs packages is 7,400 liters

should be changed to: (highlight indicates changed values)

Input	Source	Description
DTN: SN0702PAIPC1CA.001. In-Package Chemistry Calculations and Abstractions. [DIRS 186224]	file: *CDSP-2MCO Cell 1.xls*, worksheet: "WP Cell 1 Moles & Surf Areas," cell: G12	The total void volume of the codisposal waste packages containing two MCOs packages is 5,700 liters

3. FEP 2.1.03.07.0A (2nd bullet), p. 6-440:

"If an MCO fails from overpressurization, it will vent into the void volume inside the codisposal waste package. The resulting pressure is at most 104 psia at 211°C (see excluded FEP 2.1.13.01.0A (Radiolysis)), which is less than the design pressure of the waste package, 140 psia at 707°F (375°C) (BSC 2007 [DIRS 180190], Appendix B, B4.2.2)."

should be changed to: (highlight indicates changed values)

"If both MCOs fail from overpressurization, they will vent into the void volume inside the codisposal waste package. The resulting pressure is at most 84 psia at 211°C (see excluded FEP 2.1.13.01.0A (Radiolysis)), which is less than the design pressure of the waste package, 140 psia at 707°F (375°C) (BSC 2007 [DIRS 180190], Appendix B, B4.2.2)."

4. FEP 2.1.13.01.0A on page 6-778,

   “Excluded FEPs that calculate pressure effects (e.g., FEPs 2.1.03.07.0A (Mechanical Impact on Waste Package) and 2.1.12.02.0A (Gas Generation (He) From Waste Form Decay)) use a TAD canister void volume of 4,737 L (from DTN: SN0702PAIPC1.001 [DIRS 180451], file: *CSNF WP Design Cell 1.xls*, worksheet: “TAD WP Total Moles and SA,” cell: B48).”

   should be changed to: (highlight indicates changed values)

   “Excluded FEPs that calculate pressure effects (e.g., FEPs 2.1.03.07.0A (Mechanical Impact on Waste Package) and 2.1.12.02.0A (Gas Generation (He) From Waste Form Decay)) use a TAD canister void volume of 4,737 L (from DTN: SN0702PAIPC1CA.001 [DIRS 186224], file: *CSNF WP TAD Design Cell 1.xls*, worksheet: “TAD WP Total Moles and SA,” cell: B48).”

5. FEP 2.1.13.01.0A on page 6-778,

   “… the in-package chemistry “cell 1” TAD canister void volume of 4,737 L (DTN: SN0702PAIPC1.001 [DIRS 180451]) …”

   should be changed to: (highlight indicates changed values)

   “… the in-package chemistry “cell 1” TAD canister void volume of 4,737 L (DTN: SN0702PAIPC1CA.001 [DIRS 186224]) …”

6. FEP 2.1.13.01.0A on page 6-779,

   “If pressurized at 25°C to 1.5 atm (0.15 MPa or 22 psia) with helium (24.5 mole helium in 400 L void volume; DTN: SN0702PAIPC1CA.001 [DIRS 180451], file: *CDSP – 2MCO Cell 1.xls*, worksheet: “Void Space,” cell C51) and assuming all residual water is converted into H_2 and O_2 gas (358 mole gas = 1.5 × 239 mole H_2O) the design pressure of 450 psi (at 132°C; Garvin 2002 [DIRS 169141], Section 2.2.6.2) will be exceeded at about 117°C for a single MCO. The pressure inside the MCO at 211°C would reach 559 psia) (38 atm = 3.8 MPa), well beyond the design pressure.”

   should be changed to: (highlight indicates changed values)

   “If pressurized at 25°C to 1.5 atm (0.15 MPa or 22 psia) with helium (24.5 mole helium in 400 L void volume; DTN: SN0702PAIPC1CA.001 [DIRS 186224], file: *CDSP – 2MCO Cell 1.xls*, worksheet: “Void Space,” cell C51) and assuming all residual water is converted into H_2 and O_2 gas (358 mole gas = 1.5 × 239 mole H_2O) the design pressure of 450 psi (at 132°C; Garvin 2002 [DIRS 169141], Section 2.2.6.2) will be exceeded at about 117°C for a single MCO. The pressure inside the MCO at 211°C would reach 559 psia~~)~~ ({24.5+358 mol} x {0.082 L·atm·mol^{-1}·K^{-1}} x {484.15 K} ÷ [400 L] =38 atm = 559 psia ~~3.8 MPa~~), well beyond the design pressure.”

7. FEP 2.1.13.01.0A on pages 6-779 and 6-780,

"Rather, a failed MCO is expected to vent into the surrounding codisposal waste package, which has a net void volume of 3,000 L (7,400 L minus the net volumes of two MCO canisters at 1,000 L each and two HLW glass canisters at 1,200 L each; volumes from DTN: SN0702PAIPC1CA.001 [DIRS 180451], file: *CDSP – 2MCO Cell 1.xls*, worksheet: "Void Space"). It is assumed further here that the codisposal waste package will have also been pressurized to 1.5 atm with helium at 25°C (184 mole helium in 3,000 L of void volume). Combining the void volumes of the codisposal waste package and one MCO canister (3,000 + 400 = 3,400 L) indicates that the design pressure for the waste package will not be exceeded for temperatures below about 425°C, and that the pressure at 211°C would only be about 93 psia (6.3 atm = 0.64 MPa). Including the void volumes for both MCOs in the calculation increases the attainable pressure by only about 7% (e.g., 104 psia (7.1 atm = 0.71 MPa) at 211°C) if one MCO canister is assumed to contain the maximum amount of water (4.3 kg) and the second MCO canister is assumed to contain the average value of 1.03 kg (57 moles) total water (Sexton 2007 [DIRS 184742], Table 2-1).

should be changed to: (highlight indicates changed values)

"Rather, a failed MCO is expected to vent into the surrounding codisposal waste package, which has a net void volume of 4,600 ~~3,000~~ L (5,700 ~~7,400~~ L total void space minus the void spaces ~~net volumes~~ of two MCO canisters at 400 ~~1,000~~ L each and two HLW glass canisters at 150 ~~1,200~~ L each; volumes from DTN: SN0702PAIPC1CA.001 [DIRS 186224], file: *CDSP – 2MCO Cell 1.xls*, worksheets: "WP Cell 1 Moles & Surf Areas", cell: G12 and "Void Space", cells C51 and C16 respectively). It is assumed further here that the codisposal waste package will have also been pressurized to 1.5 atm with helium at 25°C (282~~184~~ mole helium in 4,600 ~~3,000~~ L of void volume). Combining the void volumes of the codisposal waste package and one MCO canister (4,600 ~~3,000~~ + 400 = 5,000 ~~3,400~~ L) indicates that the design pressure for the waste package will not be exceeded for temperatures below about 600 ~~425~~°C, and that the pressure at 211°C would only be about 78 ~~93~~ psia ({282+382.5 mol} x {0.082 L·atm·mol^{-1}·K^{-1}} x {484.15 K} ÷ [5000 L] = 5.3 ~~6.3~~ atm = 78 psia ~~0.64 MPa~~). Including the void volumes for both MCOs in the calculation increases the attainable pressure by only about 8 ~~7~~% to~~(e.g.,~~ 84 ~~104~~ psia ({24.5+85.5+664.5 mol} x {0.082 L·atm·mol^{-1}·K^{-1}} x {484.15 K} ÷ [5400 L] = 5.7 ~~7.1~~ atm = 84 psia ~~0.71 MPa~~) ~~at 211°C)~~ if one MCO canister is assumed to contain the maximum amount of water (4.3 kg) and the second MCO canister is assumed to contain the average value of 1.03 kg (57 moles) total water (Sexton 2007 [DIRS 184742], Table 2-1).

8. FEP 2.1.13.01.0A, Table 2.1.13.01.0A-1. Direct Inputs (Continued) on p. 6-790, row 2,

Input	Source	Description
DTN: SN0702PAIPC1CA.001. In-Package Chemistry Calculations and Abstractions. [DIRS 180451]	file: *CDSP 2MCO Cell 1.xls*, worksheet: “Void Space”	The TAD canister void volume is 4,737 L
	file: *CDSP 2MCO Cell 1.xls*, worksheet: “Void Space,” cell C51	The TAD canister void volume is 4,737 L
	file: *CSNF WP Design Cell 1.xls*, worksheet: “TAD WP Total Moles and SA,” cell: B48	The TAD canister void volume is 4,737 L

should be changed to: (highlight indicates values that changed)

Input	Source	Description
DTN: SN0702PAIPC1CA.001. In-Package Chemistry Calculations and Abstractions. [DIRS 186224]	file: *CDSP 2MCO Cell 1.xls*, worksheet: "WP Cell 1 Moles & Surf Areas", Cell: G12 ~~“Void Space”~~	The CDSP ~~TAD~~ canister total void volume is 5,700 ~~4,737~~ L
	file: *CDSP 2MCO Cell 1.xls*, worksheet: “Void Space,” cells C51 and C16	The MCO ~~TAD~~ canister void volume is 400 ~~4,737~~ L. The glass pour canister void volume is 150 L
	file: *CSNF WP TAD Design Cell 1.xls*, worksheet: “TAD WP Total Moles and SA,” cell: B48	The TAD canister void volume is 4,737 L

9. Section 8.3, page 8-78,

“180451 SN0702PAIPC1.001”

“Submittal date: 04/19/2007”

should be changed to: (highlight indicates changed values)

“186224 SN0702PAIPC1CA.001”

“Submittal date: 04/10/2009”

To satisfy CR 13519:

1. FEP 1.1.03.01.0A, p. 6-39, last paragraph, line 7,

   delete:

   "performance confirmation and"

2. FEP 1.1.08.00.0A, p. 6-59, last paragraph, line 5,

   delete:

   "performance confirmation and"

To satisfy CR 13666:

1. In Appendix C, p. C-15, second paragraph, line 11

   the incorrect citation [DIRS 177404] should be changed to:

   [DIRS 177407]

2. In Appendix C, p. C-18, Table C-2, row 2, "Input"

   should be changed to:

   SNL 2007. EBS Radionuclide Transport Abstraction [DIRS 177407]

3. The DIRS report is also corrected to reflect the correct citation.

To satisfy CR 13735:

1. FEP 2.1.03.04.0A, p. 6-414, last paragraph,

   line 3 should be changed to add:

   "for the nominal scenario case (i.e., not seismic or igneous)," after "Likewise,"

   line 7 should be changed to add:

   "(e.g., after the repository is disrupted by a seismic or igneous event)" after " ... in the support structure or invert"

2. FEP 2.1.06.05.0C, p. 6-522, second paragraph in "Disposition", last line

   should be changed to add:

   "for the nominal scenario case" after "… Type 316"

3. FEP 2.1.06.05.0C, p. 6-522, third paragraph in "Disposition", line 3

   should be changed to add:

   "for the nominal scenario case (i.e., not seismic or igneous)" after "… drift components"

4. FEP 2.1.06.07.0A, p. 6-538, first paragraph, line 16

   should be changed to add:

   "for the nominal scenario case (i.e., not seismic or igneous)" after "… this interface"

5. FEP 2.1.09.09.0A, p. 6-651, fourth paragraph in “Disposition”, line 1

   should be changed to add:

   “for the nominal scenario case (i.e., not seismic or igneous),” after “… repository closure,”

To satisfy CR 13746:

1. FEP 1.3.07.02.0B, p. 6-234, just prior to “Inputs”

   add the following paragraph:

   The potential for flooding of the repository is addressed in FEPs 2.1.07.04.0A (Hydrostatic Pressure on Waste Package) and 2.1.07.04.0B (Hydrostatic Pressure on Drip Shield). Those exclusion arguments were based on low probability because the repository is designed such that waste will be emplaced within the unsaturated zone well above the water table, and it is very unlikely that the water table will rise to the level of the repository.

To address impacts from Screening Analysis of Criticality Features, Events, and Processes, (ANL-DS0-NU-0000001 Rev 00 ERD 05):

[NOTE—Some related impacts that satisfied CR 13156 were previously identified in ANL-WIS-MD-000027 REV 00 ERD 04. They are not repeated here.]

1. FEP 2.1.14.15.0A, p. 6-803, second paragraph:

   “the absence and/or loss of efficacy of the neutron absorber plates”

   should be replaced by:

   “improper performance of the neutron absorber”

   and delete:

   “of plates” before “outside specified range)”.

2. FEP 2.1.14.15.0A, p. 6-803, numbered item 1,

   delete:

   “plates” after “neutron absorber”

3. FEP 2.1.14.15.0A, p. 6-807, fourth calculation description,

   should be changed to add:

   “plate” after “DOE SNF canister absorber”.

4. FEP 2.1.14.15.0A, p. 6-807, first paragraph (after the calculations),

   Thus, a conservative estimate for the probability of achieving a configuration with criticality potential in the repository due to the presence of weld flaws in the OCB closure lid or other early failure mechanisms, based on summing this set of events, including the DOE1, DOE2, and DOE7 contributions is 2.1×10^{-7} for 10,000 years. Since the events in the above evaluation are all associated with operations during the preclosure period, the probabilities are constant over the postclosure time period. It should be noted that the other DOE criticality SNF groups do not pose a criticality concern because they do not need to rely on neutron absorber plates for criticality control. These evaluations are demonstrated in DOE SNF Phase I and II Summary Report (Radulescu et al. 2004 [DIRS 165482]), Intact and Degraded Mode Criticality Calculations for the Codisposal of TMI-2 Spent Nuclear Fuel in a Waste Package (BSC 2004 [DIRS 168935]), and Intact and Degraded Mode Criticality Calculations for the Codisposal of ATR Spent Nuclear Fuel in a Waste Package (BSC 2004 [DIRS 171926]).

should be changed to:

Evaluating the event sequences for DOE SNF accounting for the probability of neutron absorber shot misload for the DOE1 (MOX), DOE5 (U/Th Oxide), and DOE8 (U-Zr/U-Mo alloy) waste forms, the estimated canister misload probability for these waste forms is given by:

> DOE SNF canister absorber shot misload (214 DOE1, DOE5, and DOE8 canisters, SNL 2008 [DIRS 173869], Section 6.3.2):
> $\{1\text{-}P_B\ (0; ((3.77 \times 10^{-5} \times 1.25 \times 10^{-3} + 1.13\ \times 10^{-4} + 2.19 \times 10^{-9} \times 1.0) \times 1.25 \times 10^{-7}), 214)\} = 3.0 \times 10^{-9}$.

Thus, a conservative estimate for the probability of achieving a configuration with criticality potential in the repository due to early failure initiating events, based on summing the results above, combining the DOE1 (absorber plate and shot error), DOE2, DOE5, DOE7, and DOE8 contributions is 2.1 × 10^{-7} for 10,000 years. Since the events in the above evaluation are all associated with operations during the preclosure period, the probabilities are constant over the postclosure time period.

5. FEP 2.1.14.19.0A, p. 6-821, title of Table 2.14.19.0A-1, replace:

   "Causing" **with** "with Potential to Cause"

6. FEP 2.1.14.19.0A, p. 6-821, Source of Table 2.14.19.0A-1, replace:

   [DIRS 184958] with [DIRS 186328]

7. FEP 2.1.14.19.0A, p. 6-822, title of Table 2.14.19.0A-2, replace:

   "Causing" **with** "with Potential to Cause"

8. FEP 2.1.14.19.0A, p. 6-822, first paragraph (after Table 2.1.14.19.0A-2),

   Probability of waste package OCB damage from effects of the ground motion—If a seismic vibratory ground motion event occurs, the estimated probability of damage to a TAD canister-bearing waste package from impacts is given as 0.118 (SNL 2007 [DIRS 176828], Section 6.5.1.2) at the 90% RST level at the 4.07 m/s PGV range, resulting in a probability of damage for a TAD canister-bearing waste package given by 4.41 × 10^{-3} × (0.0 + 0.118) × 0.5 = 2.6 × 10^{-4}. The probability of damage at the 100% RST level is zero. Since the probability of damage (i.e., 0.118) is a point estimate evaluated at discrete PGV levels, the probability over the frequency range is assigned the average value. The 90% RST level data is used for conservatism for the initiating event probability values.

should be changed to: (highlight indicates changed values)

Probability of waste package OCB damage from effects of the ground motion—If a seismic vibratory ground motion event occurs, the estimated probability of damage to a TAD canister-bearing waste package from impacts is given as 0.118 (SNL 2007 [DIRS 176828], Section 6.5.1.2) at the 90% RST level at the 4.07 m/s PGV range. Integrating over the distribution for seismic hazard (Tables 2.1.14.19.0A-1 and 2.1.14.19.0A-2) results in a probability of damage for a TAD waste package given by Table 2.1.14.19.0A-3 as 1.57 × 10^{-4} for the 90% RST level, and zero for a damage threshold at either the 100% and 105% RST levels. The 90% RST level data is used for conservatism for the initiating event probability values.

9. FEP 2.1.14.19.0A, p. 6-822, second paragraph,

Similarly, the estimated probability of damage to a codisposal waste package from impacts is given in Table 2.1.14.19.0A-3 at the 90% RST level for PGV values between 0.4 and 4.07 m/s inclusively and at 100% RST level for PGV values between 2.44 and 4.07 m/s inclusively.

should be changed to: (highlight indicates changed values)

Similarly, the estimated probability of damage to a codisposal waste package from impacts is given in Table 2.1.14.19.0A-3, assuming a damage threshold at the 90% RST level, resulting in a probability of damage to a codisposal waste package of 0.196 and 0.004 at the 90% and 100% RST levels, respectively. The estimated probability of damage from impacts for a codisposal waste package is zero, assuming a damage threshold at the 105% RST level. The 90% RST level data is used for conservatism for the initiating event probability values.

10. FEP 2.1.14.19.0A, p. 6-822, Source of Table 2.14.19.0A-2, replace:

    [DIRS 184958] with [DIRS 186328]

11. FEP 2.1.14.19.0A, p. 6-822, replace Table 2.1.14.19.0A-3 with:

Table 2.1.14.19.0A-3. Integrated Probability of Damage Due to Seismic Vibratory Ground Motion

RST (%)	**CDSP**		**CSNF**	
	Damage Frequency (yr^{-1})[a]	**P_D**	**Damage Frequency (yr^{-1})[b]**	**P_D**
90	2.181 × 10^{-5}	0.196	1.575 × 10^{-8}	1.57 × 10^{-4}
100	4.242 × 10^{-7}	0.004	0	0
	Expected Value of Distribution for RST			
90 to 105	7.484 × 10^{-6}	0.072	5.249 × 10^{-9}	5.25 × 10^{-5}

Sources: [a] DTN: MO0708CDSPSEIS.000 [DIRS 183007], FreqDamageCDSP_v5.pdf
[b] DTN: MO0708FREQCALC.000 [DIRS 183006]. FreqDamageTAD.pdf

12. FEP 2.1.14.19.0A, p. 6-822, delete the last paragraph (which continues onto p. 6-823).
13. FEP 2.1.14.19.0A, p. 6-823, second paragraph,

    delete:

    "of plates" from line 2, and

    "plates" from line 8.
14. FEP 2.1.14.19.0A, p. 6-824, lines 1 and 2,

    "MO0712PBANLNWP.000 [DIRS 184664]"

    should be changed to: (highlight indicates changed values)

    "MO0810PBANLNWP.001 [DIRS 185947]"
15. FEP 2.1.14.19.0A, p. 6-824, line 7,

    "MO0712PANLNNWP.000 [DIRS 184480]"

    should be changed to: (highlight indicates changed values)

    "MO0810PANLNNWP.001 [DIRS 185842]"
16. FEP 2.1.14.19.0A, p. 6-824, line 8,

    "MO0712PBANLNWP.000 [DIRS 184664]"

    should be changed to: (highlight indicates changed values)

    "MO0810PBANLNWP.001 [DIRS 185947]"

17. FEP 2.1.14.19.0A, p. 6-824, Table 2.1.14.19.0A-4, column "Probability",

    change the values in the four rows to:

    7.2 x 10^{-9}

    5.5 x 10^{-9}

    3.5 x 10^{-9}

    4.1 x 10^{-10}
18. FEP 2.1.14.19.0A, p. 6-824, first calculation,

    change: (highlight indicates changed values)

    2.6 x 10^{-4} to 1.57 x 10^{-4}, and 2.0 x 10^{-7} to 1.2 x 10^{-7}
19. FEP 2.1.14.19.0A, p. 6-824, second calculation,

    change: (highlight indicates changed values)

    2.6 x 10^{-4} to 1.57 x 10^{-4}, and 1.5 x 10^{-7} to 9.0 x 10^{-8}
20. FEP 2.1.14.19.0A, p. 6-824, third calculation,

    change: (highlight indicates changed values)

2.6 x 10^{-4} to 1.57 x 10^{-4}, and 9.5 x 10^{-8} to 5.7 x 10^{-8}

21. FEP 2.1.14.19.0A, p. 6-824, fourth calculation,

    change: (highlight indicates changed values)

    0.24 to 0.196, and 3.7 x 10^{-5} to 3.0 x 10^{-5}

22. FEP 2.1.14.19.0A, p. 6-824, fourth calculation description,

    should be changed to add:

    "plate" after "canister absorber".

23. FEP 2.1.14.19.0A, p. 6-824, last paragraph (which continues onto p. 6-825):

    Thus, a conservative estimate for the probability of achieving a configuration with criticality potential in the repository resulting from seismic vibratory induced impact damage, assuming a damage threshold at the 90% RST level, with subsequent SCC breaching of the waste package OCB for commercial SNF and DOE SNF, based on summing this set of events, including the DOE1, DOE2, and DOE7 contributions, is 3.7 × 10−5 for 10,000 years. In actuality, the number of DOE waste packages that have sufficient criticality potential to require absorber plate criticality control is much less than 1,223 packages. Therefore, an example estimate using only the DOE2 contribution (89 waste packages), is 3.1 × 10−6 for 10,000 years. These results have been developed on a very conservative basis (e.g., use of damage probabilities at the 90% RST level and a maximum of five intervals to represent the seismic hazard curve). The probabilities evaluated from complete event sequences are expected to be significantly lower than from using a truncated sequence of events to estimate the probability of achieving a configuration with potential for criticality. For example, using a maximum of 35 intervals in the hazard curve for estimating the probability of impact damage to codisposal waste packages reduced the estimated probability of vibratory impact damage to the codisposal waste packages by approximately 20% (DTN: MO0705CRITPROB.000 [DIRS 184958], file: CSNF TAD & CDSP WP Impact damage.xls).

    should be changed to: (highlight indicates changed values)

    Evaluating the event sequences for DOE SNF accounting for the probability of neutron absorber shot misload for the DOE1 (MOX), DOE5 (U/Th Oxide), and DOE8 (U-Zr/U-Mo alloy) waste forms, the estimated canister misload probability for these waste forms is given by:

    DOE SNF canister absorber shot misload (214 DOE1, DOE5, and DOE8 canisters,
    SNL 2008 [DIRS 173869], Section 6.4.2.1):

    $0.196 \times \{1-\mathrm{PB}\ (0; (1.25 \text{ x } 10^{-7}), 214)\} = 5.2 \times 10^{-6}$

    Thus, a conservative estimate for the probability of achieving a configuration with criticality potential in the repository resulting from seismic vibratory induced impact damage, assuming a damage threshold at the 90% RST level, with subsequent SCC breaching of the waste package OCB for commercial SNF and DOE SNF, based on summing this set of events, combining the DOE1 (absorber plate and shot error), DOE2, DOE5, DOE7, and DOE8 contributions is 3.5 x 10^{-5} for 10,000 years

(SNL 2008 [DIRS 173869], Section 6.4.2.1). These results have been developed on a very conservative basis (e.g., use of damage probabilities at the 90% RST level). The probabilities evaluated from the complete event sequences are expected to be significantly lower than from using a truncated sequence of events to estimate the probability of achieving a configuration with potential for criticality.

24. FEP 2.1.14.19.0A, p. 6-826, Source of Table 2.14.19.0A-5, replace:

    [DIRS 184958] with [DIRS 186328]

25. FEP 2.1.14.19.0A, p. 6-826, Source of Table 2.14.19.0A-6, replace:

    [DIRS 184958] with [DIRS 186328]

26. FEP 2.1.14.19.0A, p. 6-826, Source of Table 2.14.19.0A-7, replace:

    [DIRS 184958] with [DIRS 186328]

27. FEP 2.1.14.19.0A, p. 6-827, Source of Table 2.14.19.0A-8, replace:

    [DIRS 184958] with [DIRS 186328]

28. FEP 2.1.14.19.0A, p. 6-827, Source of Table 2.14.19.0A-9, replace:

    [DIRS 184958] with [DIRS 186328]

29. FEP 2.1.14.19.0A, p. 6-828, first calculation,

    in line 2, delete:

    "-19.4" and "-27.6"

    in line 3 change: (highlight indicates changed values)

    6.3×10^{-10} to 1.9×10^{-9}

30. FEP 2.1.14.19.0A, p. 6-828, second calculation,

    in line 2, delete:

    "-19.4" and "-27.6"

    in line 3 change: (highlight indicates changed values)

    4.8×10^{-10} to 1.4×10^{-9}

31. FEP 2.1.14.19.0A, p. 6-828, third calculation,

    in line 2, delete:

    "-19.4" and "-27.6"

    in line 3 change: (highlight indicates changed values)

    2.9×10^{-10} to 9.0×10^{-10}

32. FEP 2.1.14.19.0A, p. 6-828, fourth calculation description,

    should be changed to add:

    "plate" after "DOE SNF canister absorber".

33. FEP 2.1.14.19.0A, p. 6-828, fourth calculation,

    in line 2, delete:

    "-2.6", "-3.5", and "-3.7"

    in line 3, delete:

    "-4.9", "-4.3", and "-5.7"

    in line 4 change: (highlight indicates changed values)

    8.1 x 10^{-11} to 5.4 x 10^{-10}

34. FEP 2.1.14.19.0A, p. 6-828, first paragraph (after the calculations),

    Thus, a conservative estimate for the probability of achieving a configuration with criticality potential in the repository resulting from a seismic faulting initiating event for commercial SNF and DOE SNF is 1.5×10^{-9} for 10,000 years.

    should be changed to: (highlight indicates changed values)

    Evaluating the event sequences for DOE SNF with the probability of neutron absorber shot misload for the DOE1 (MOX), DOE5 (U/Th Oxide), and DOE8 (U-Zr/U-Mo alloy) waste forms is given by:

    > DOE SNF canister absorber shot misload (214 DOE1, DOE5, and DOE8 canisters, (SNL 2008 [DIRS 173869], Section 6.4.3):
    > $1.0 \times 10^{-4} \times (1-P_B\ (0;\ 1.25 \times 10^{-7}, (2.6+3.5) \times 214/3074)) + 6.9 \times 10^{-4} \times (1-P_B\ (0;\ 1.25 \times 10^{-7}, (3.7 + 4.9) \times 214/3074)) + 2.8 \times 10^{-4} \times (1-P_B\ (0;\ 1.25 \times 10^{-7}, (4.3 + 5.7) \times 214/3074)) + 3.0 \text{ x } 10^{-5} \times (1-P_B\ (0;\ 1.25 \times 10^{-7}, (21.6 + 28.5) \times 214/3074)) = 9.4 \times 10^{-11}$.

    Thus, a conservative estimate for the probability of achieving a configuration with criticality potential in the repository resulting from a seismic faulting initiating event for commercial SNF and DOE SNF, combining the DOE1 (absorber plate and shot error), DOE2, DOE5, DOE7, and DOE8 contributions is 4.8×10^{-9} for 10,000 years.

35. FEP 2.1.14.19.0A, p. 6-829, first paragraph, line 1

    "3.7×10^{-5} over 10,000 years."

    should be changed to: (highlight indicates changes)

    " 3.55×10^{-5} over 10,000 years (SNL 2008 [DIRS 173869] Table 7.1-1)."

36. FEP 2.1.14.19.0A, p. 6-829, Table 2.1.14.19.0A-10, row 5, "Input"

    The DIRS number for DTN: MO0705CRITPROB.000 should be changed to:

    "186328"

37. FEP 2.1.14.19.0A, p. 6-830, Table 2.14.19.0A-10, in first line of "Input" replace:

    [DIRS 184958] with [DIRS 186328]

38. FEP 2.1.14.19.0A, p. 6-832, Table 2.1.14.19.0A-11, row 5,

    in "Citation" column, change: (highlight indicates changed values)

    "MO0712PANLNNWP.000" to "MO0810PANLNNWP.001"

    In "DIRS" column, change: (highlight indicates changed values)

    "184480" to "185842"

39. FEP 2.1.14.19.0A, p. 6-832, Table 2.1.14.19.0A-11, row 6,

    in "Citation" column, change: (highlight indicates changed values)

    "MO0712PBANLNWP.000" to "MO0810PBANLNWP.001"

    In "DIRS" column, change: (highlight indicates changed values)

    "184664" to "185947"

40. Section 8.3, page 8-76,

    "184958 MO0705CRITPROB.000. Probability of Criticality. Submittal date: 02/05/2008."

    should be changed to: (highlight indicates changed values)

    "186328 MO0705CRITPROB.000. Probability of Criticality. Submittal date: 08/20/2009."

41. Section 8.3, page 8-77,

    "184480 MO0712PANLNNWP.000. Probabilistic Analysis of Drip Shield Failure and CSNF and CDSP Package OCB Localized Corrosion. Submittal date: 12/17/2007."

    should be changed to: (highlight indicates changed values)

    "185842 MO0810PANLNNWP.001. Probabilistic Analysis of Drip Shield Failure and CSNF and CDSP Package OCB Localized Corrosion. Submittal date: 10/21/2008."

42. Section 8.3, page 8-77,

    "184664 MO0712PBANLNWP.000. Probabilistic Analysis of Navy Waste Packages. Submittal date: 12/13/2007."

    should be changed to: (highlight indicates changed values)

    "185947 MO0810PBANLNWP.001. Probabilistic Analysis of Navy Waste Packages (Correction). Submittal date: 10/21/2008."

Additional Changes

To satisfy CR 13666, a typo was found and corrected in a citation of SNL 2007 *EBS Radionuclide Transport Abstraction* [DIRS 177407]. While making this correction, it was noted that there were a number of instances throughout the report where the citation was incorrectly listed as SNL 2008 [DIRS 177407]. This is not a valid citation as the correct reference and DIRS entry is SNL 2007 [DIRS 177407]. The Table below lists the instances where "SNL 2008" needs to be changed to "SNL 2007" to be consistent with the cited reference and the correct DIRS number. Adobe Acrobat representations of each of these changed pages are not provided (except for page 6-340, which was also corrected as part of CR 13416).

Incorrect Citation	Citation Corrected To	Location
SNL 2008 [DIRS 177407]	SNL 2007 [DIRS 177407]	page 6-335 (2 instances)
SNL 2008 [DIRS 177407]	SNL 2007 [DIRS 177407]	page 6-339
SNL 2008	SNL 2007	page 6-340
SNL 2008 [DIRS 177407]	SNL 2007 [DIRS 177407]	page 6-453
SNL 2008 [DIRS 177407]	SNL 2007 [DIRS 177407]	page 6-457
SNL 2008 [DIRS 177407]	SNL 2007 [DIRS 177407]	page 6-463 (2 instances)
SNL 2008	SNL 2007	Page 6-465 column 1, 17th row
SNL 2008 [DIRS 177407]	SNL 2007 [DIRS 177407]	page 6-477 (2 instances)
SNL 2008	SNL 2007	Page 6-480 column 1, 8th row
SNL 2008 [DIRS 177407]	SNL 2007 [DIRS 177407]	page 6-482
SNL 2008	SNL 2007	Page 6-483 column 1, 5th row
SNL 2008 [DIRS 177407]	SNL 2007 [DIRS 177407]	page 6-520 (3 instances)
SNL 2008	SNL 2007	Page 6-521 Table 1 column 1, 1st row
SNL 2008	SNL 2007	Page 6-521 Table 2 column 1, 3rd row
SNL 2008 [DIRS 177407]	SNL 2007 [DIRS 177407]	page 6-524 (3 instances)
SNL 2008	SNL 2007	Page 6-526 Table 2 column 1, 8th row
SNL 2008 [DIRS 177407]	SNL 2007 [DIRS 177407]	page 6-527 (2 instances)
SNL 2008 [DIRS 177407]	SNL 2007 [DIRS 177407]	page 6-528 (2 instances)
SNL 2008	SNL 2007	Page 6-529 column 1, 2nd row
SNL 2008	SNL 2007	Page 6-529 column 1, 4th row
SNL 2008 [DIRS 177407]	SNL 2007 [DIRS 177407]	page 6-530
SNL 2008 [DIRS 177407]	SNL 2007 [DIRS 177407]	page 6-531 (2 instances)
SNL 2008 [DIRS 177407]	SNL 2007 [DIRS 177407]	page 6-532 (2 instances)
SNL 2008	SNL 2007	Page 6-533 column 1, 4th row
SNL 2008 [DIRS 177407]	SNL 2007 [DIRS 177407]	page 6-583 (3 instances)
SNL 2008	SNL 2007	Page 6-583 column 1, 3rd row
SNL 2008 [DIRS 177407]	SNL 2007 [DIRS 177407]	page 6-586 (3 instances)
SNL 2008	SNL 2007	Page 6-587 column 1, 3rd row
SNL 2008 [DIRS 177407]	SNL 2007 [DIRS 177407]	page 6-588 (4 instances)
SNL 2008 [DIRS 177407]	SNL 2007 [DIRS 177407]	page 6-589 (5 instances)
SNL 2008 [DIRS 177407]	SNL 2007 [DIRS 177407]	page 6-590 (2 instances)
SNL 2008	SNL 2007	Page 6-590 column 1, 4th row
SNL 2008 [DIRS 177407]	SNL 2007 [DIRS 177407]	page 6-591 (4 instances)
SNL 2008	SNL 2007	Page 6-592 column 1, 3rd row
SNL 2008 [DIRS 177407]	SNL 2007 [DIRS 177407]	page 6-593 (3 instances)
SNL 2008 [DIRS 177407]	SNL 2007 [DIRS 177407]	page 6-594 (9 instances)
SNL 2008	SNL 2007	Page 6-595 column 1, 3rd row
SNL 2008 [DIRS 177407]	SNL 2007 [DIRS 177407]	page 6-596 (2 instances)
SNL 2008 [DIRS 177407]	SNL 2007 [DIRS 177407]	page 6-597 (2 instances)
SNL 2008	SNL 2007	Page 6-598 column 1, 2nd row
SNL 2008	SNL 2007	Page 6-598 column 1, 3rd row
SNL 2008 [DIRS 177407]	SNL 2007 [DIRS 177407]	page 6-609
SNL 2008	SNL 2007	Page 6-611 column 1, 6th row
SNL 2008 [DIRS 177407]	SNL 2007 [DIRS 177407]	page 6-613
SNL 2008	SNL 2007	Page 6-614 column 1, 3rd row
SNL 2008 [DIRS 177407]	SNL 2007 [DIRS 177407]	page 6-618
SNL 2008 [DIRS 177407]	SNL 2007 [DIRS 177407]	page 6-619
SNL 2008	SNL 2007	Page 6-619 column 1, 2nd row
SNL 2008 [DIRS 177407]	SNL 2007 [DIRS 177407]	page 6-620
SNL 2008 [DIRS 177407]	SNL 2007 [DIRS 177407]	page 6-621
SNL 2008 [DIRS 177407]	SNL 2007 [DIRS 177407]	page 6-622
SNL 2008	SNL 2007	Page 6-622 column 1, 2nd row
SNL 2008 [DIRS 177407]	SNL 2007 [DIRS 177407]	page 6-629
SNL 2008 [DIRS 177407]	SNL 2007 [DIRS 177407]	page 6-630
SNL 2008	SNL 2007	Page 6-633 column 1, 8th row

Incorrect Citation	Citation Corrected To	Location
SNL 2008 [DIRS 177407]	SNL 2007 [DIRS 177407]	page 6-638 (2 instances)
SNL 2008 [DIRS 177407]	SNL 2007 [DIRS 177407]	page 6-639 (3 instances)
SNL 2008	SNL 2007	Page 6-639 column 1, 2nd row
SNL 2008 [DIRS 177407]	SNL 2007 [DIRS 177407]	page 6-645
SNL 2008	SNL 2007	Page 6-645 column 1, 1st row

IV. Impact Evaluation/Results:

These corrections do not impact the conclusions or output from *Features, Events, and Processes for the Total System Performance Assessment: Analyses* or any of its downstream documents. This ERD impacts DTN: MO0706SPAFEPLA.001, FY 2007 LA FEP List and Screening.

The following controlled documents that cite ANL-WIS-MD-000027 REV 00 [DIRS 183041] were checked for impacts as a result of these corrections:

- ANL-EBS-MD-000033, Rev 06, *Engineered Barrier System: Physical and Chemical Environment.*
- ANL-EBS-MD-000049, Rev 03, Addendum 01, *Multiscale Thermohydrologic Model.*
- ANL-EBS-PA-000011, Rev 00, *Postclosure Design Input Parameters for Engineered Barrier System In-Drift Configuration.*
- ANL-EBS-PA-000012, Rev 00, *Postclosure Design Input Parameters for Subsurface Facilities.*
- ANL-EBS-PA-000013, Rev 00, *Postclosure Design Input Parameters for Waste Package Outer Barrier and Inner Vessels.*
- ANL-EBS-PA-000014, Rev 00, *Postclosure Design Input Parameters for Waste Forms and Internals.*
- ANL-NBS-HS-000057, Rev 00, *Postclosure Analysis of the Range of Design Thermal Loadings.*
- ANL-WIS-MD-000024, Rev 01, *Postclosure Nuclear Safety Design Bases*.
- ANL-WIS-MD-000026, Rev 00, *Features, Events, and Processes for the Total System Performance Assessment: Methods.*
- CAL-DN0-NU-000002, Rev 00C, *Waste Package Flooding Probability Evaluation.*
- MDL-MGR-HS-000001, Rev 00, ACN 01, *Irrigation Recycling Model.*
- MDL-MGR-MD-000001, Rev 02, *Biosphere Model Report.*
- MDL-NBS-HS-000011, Rev 03, *Saturated Zone Site-Scale Flow Model*.

- MDL-WIS-PA-000005, Rev 00, *Total System Performance Assessment Model/Analysis for the License Application – Volume I.*
- MDL-WIS-PA-000005, Rev 00, *Total System Performance Assessment Model/Analysis for the License Application – Volume III.*
- TDR-PCS-SE-000001, Rev 05, Addendum 01, *Performance Confirmation Plan*.
- LA-SAR.

No impacts were observed.

The Final Environmental Impact Statement and Final Supplemental Environmental Impact Statement were also checked for impacts as a result of these corrections and no impacts were observed.

ATTACHMENT I

ADOBE ACROBAT REPRESENTATIONS OF CHANGED PAGES

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ATTACHMENT I
ADOBE ACROBAT REPRESENTATION OF CHANGED PAGES

The document pages listed here are Adobe Acrobat representations of the changes described in this ERD and maintain their original footers and associated published date.

CR 13392:

FEP 2.1.07.05.0B, p. 6-565

Table 2.1.07.05.0B-1, p. 6-567

CR 13416:

FEP 2.1.02.08.0A, p. 6-337

FEP 2.1.02.08.0A Table 2.1.02.08.0A-1 Direct Inputs (Continued), p. 6-340

FEP 2.1.03.07.0A, p. 6-440

FEP 2.1.13.01.0A, p. 6-778

FEP 2.1.13.01.0A, p. 6-779

FEP 2.1.13.01.0A, p. 6-780

FEP 2.1.13.01.0A, Table 2.1.13.01.0A-1 Direct Inputs (Continued), p. 6-790

Section 8.3, p. 8-78

CR 13519:

FEP 1.1.03.01.0A, p. 6-39

FEP 1.1.08.00.0A, p. 6-59

CR 13666:

Appendix C, p. C-15

Appendix C, p. C-18

CR 13735:

FEP 2.1.03.04.0A, p. 6-414

FEP 2.1.06.05.0C, p. 6-522

FEP 2.1.06.07.0A, p. 6-538

FEP 2.1.09.09.0A, p. 6-651

CR 13746:

FEP 1.3.07.02.0B, p. 6-234

Impacts from ANL-DS0-NU-0000001 Rev 00 ERD 05:

FEP 2.1.14.15.0A, p. 6-803

FEP 2.1.14.15.0A, p. 6-807

FEP 2.1.14.19.0A, p. 6-821

FEP 2.1.14.19.0A, p. 6-822

FEP 2.1.14.19.0A, p. 6-823

FEP 2.1.14.19.0A, p. 6-824

FEP 2.1.14.19.0A, p. 6-825

FEP 2.1.14.19.0A, p. 6-826

FEP 2.1.14.19.0A, p. 6-827

FEP 2.1.14.19.0A, p. 6-828

FEP 2.1.14.19.0A, p. 6-829

FEP 2.1.14.19.0A, p. 6-830

FEP 2.1.14.19.0A, p. 6-832

Section 8.3, p. 8-76

Section 8.3, p. 8-77

FEP: 1.1.03.01.0A

FEP NAME:

Error in Waste Emplacement

FEP DESCRIPTION:

Deviations from the design and/or errors in waste emplacement could affect long-term performance of the repository. A specific example of such an error would be erroneously emplacing the waste packages in a saturated or wet zone of the repository. Errors of this type would impact repository performance by affecting waste package corrosion and radionuclide transport.

SCREENING DECISION:

Excluded – by regulation

SCREENING JUSTIFICATION:

Possible types of waste emplacement errors are emplacement of packages closer to each other than in the design specification, and emplacement of a package so that it straddles a known Quaternary fault with potential for significant displacement. The emplacement of waste packages in a wet zone (i.e., zones of potential seepage) is not an erroneous emplacement, and is expected, and is included in the TSPA (see included FEP 2.1.08.01.0A (Water Influx at the Repository)). Saturated conditions are not expected in the repository (see excluded FEP 2.1.08.09.0A (Saturated Flow in the EBS)).

Inherent in the approach to FEP evaluation is the expectation that the repository be constructed, operated, and closed according to the design used as the basis for FEP screening and in accordance with NRC license requirements. Repository construction, operation, and closure will be subject to a quality assurance program and quality control procedures that will evaluate and disposition any deviations from the design. Of particular relevance, control procedures imposed during the repository operation phase will aim to ensure that any errors in waste emplacement are rectified before repository closure.

Inadequate quality controls on operational issues such as these are discussed in detail in excluded FEP 1.1.08.00.0A (Inadequate Quality Control and Deviations from Design), and are excluded from the performance assessments. As a result of the rigorous quality assurance/quality control requirements governing emplacement of waste packages and inspection and approval of such emplacement, errors in emplacement location resulting in waste packages being placed substantially closer to each other than specified by design, or being placed on a known fault, are not expected. The regulatory requirements for ~~performance confirmation and~~ quality assurance require that any deviation from design be evaluated for potential impact, and that significant deviations which are detected during the operational period be corrected. Erroneous emplacement of waste packages is not expected because of quality controls.

constructed in phases. The development of the subsurface facility will proceed while emplacement operations are conducted in the completed drifts and will be done in a manner that safely accommodates waste package emplacement. Phased construction and operation provides an opportunity for orderly implementation of lessons learned and incorporation of new information that would improve the safety of construction and operations. The repository will implement a management system that includes the evaluation of changes, tests, and experiments. Lessons learned and new information will be evaluated against the criteria in 10 CFR 63.44 [DIRS 180319], and the lessons learned or new information will be implemented following construction authorization or license amendment if any of the criteria are met; otherwise, the proposed changes will be implemented and documented in updates to the SAR. This is consistent with the National Research Council's description of staged development that allows for proposed adaptation without unacceptable impacts on safety or waste isolation (National Research Council 1995 [DIRS 100018], Chapter 3), incorporation of new knowledge on features and processes that determine repository performance, and accommodation of significant changes in repository requirements.

Finally, 10 CFR 63.51 [DIRS 180319] requires the DOE to submit an application to amend the license before permanent closure of a geologic repository. The submission must include an update of the assessment of the performance of the geologic repository for the period after permanent closure. The updated assessment must include any performance confirmation data collected under the program required by Subpart F, and pertinent to compliance with 10 CFR 63.113 [DIRS 180319]. This ensures that effectiveness of the engineered barriers are evaluated with respect to any significant deviations from design during construction and operation of the repository.

In summary, FEP 1.1.08.00.0A (Inadequate Quality Control and Deviations from Design) is excluded from the performance assessments conducted to demonstrate compliance with proposed 10 CFR 63.311 and 63.321 (70 FR 53313 [DIRS 178394]), and with 10 CFR 63.331 [DIRS 180319], on the basis of low consequence. In addition, the regulatory requirements for ~~performance confirmation and~~ quality assurance require that any deviation from design during the operational period be evaluated for potential impact, and that deviations with a significant adverse impact on postclosure performance be corrected.

INPUTS:

Table 1.1.08.00.0A-1. Direct Inputs

Input	Source	Description
10 CFR 63. 2007. Energy: Disposal of High-Level Radioactive Wastes in a Geologic Repository at Yucca Mountain, Nevada [DIRS 180319]	10 CFR 63.51	Requires the DOE to submit an application to amend the license before permanent closure of a geologic repository
	10 CFR 63.43	After the NRC authorizes construction of the repository, changes to the repository design or procedures as described in the SAR will be subject to license specification

The particles removed from the volume between the old and new water tables immediately enter the saturated zone.

Paleoclimate data indicate that the historical water table has never risen to the level of the repository (Forester et al. 1999 [DIRS 109425], pp. 46 to 56). Based on analysis of mineralogic alteration (zeolitization and tridymite distribution) and strontium isotope ratios, and groundwater flow modeling, the water table for future climates (both monsoon and glacial transition) is specified in *Particle Tracking Model and Abstraction of Transport Processes* (SNL 2008 [DIRS 184748], Section 6.4.8). Future climate flow fields, implemented in the UZ flow model (SNL 2007 [DIRS 184614], Section 6.6.2.2), have been postprocessed using WTRISE.

In accordance with proposed 10 CFR 63.342(c) (70 FR 53313 [DIRS 178394]), the effects of climate change after 10,000 years, but within the period of geologic stability, are represented by the NRC-prescribed distribution of percolation rates at repository depth. The TSPA model simulations use four flow fields to represent this distribution (SNL 2007 [DIRS 184614], Section 6.6.2.2). The water table rise assumed in the TSPA for the post-10,000-year period is the same as that assumed for future climates in the pre-10,000-year period.

The effect of water table rise on the thermal regime is not included in the TSPA because the exact boundary condition values for temperature, gas pressure, and saturation are not important for thermal-hydrologic seepage model results. The temperature and gas pressure values that define the initial temperature and pressure fields, respectively, are significantly altered in the near-field rock early in the simulations once the drifts heat up.

INPUTS:

Table 1.3.07.02.0B-1. Indirect Inputs

Citation	Title	DIRS
70 FR 53313	Implementation of a Dose Standard After 10,000 Years	178394
BSC 2004	*Development of Numerical Grids for UZ Flow and Transport Modeling*	169855
Forester et al. 1999	*The Climatic and Hydrologic History of Southern Nevada During the Late Quaternary*	109425
WTRISE V. 2.0	PC/WINDOWS 2000/98; DEC ALPHA/OSF1 V5.1. 10537-2.0-00.	163453
SNL 2007	*UZ Flow Models and Submodels*	184614
SNL 2008	*Particle Tracking Model and Abstraction of Transport Processes*	184748

The potential for flooding of the respository is addressed in FEPs 2.1.07.04.0A (Hydrostatic Pressure on Waste Package) and 2.1.07.04.0B (Hydrostatic Pressure on Drip Shield). Those exclusion arguments were based on low probability because the repository is designed such that waste will be emplaced within the unsaturated zone well above the water table, and it is very unlikely that the water table will rise to the level of the repository.

MCOs containing the maximum Mark IV fuel load with scrap basket, which was used because of initial exposed surfaces of uranium.) (Garvin 2002 [DIRS 169141], Table 4-4) to moles: (3,804 + 1,832) kg uranium × 1,000 g/kg ÷ 238 g uranium/mol = 23,689 moles uranium per MCO. Because there are two MCOs per waste package, there are 47,378 moles uranium metal per waste package. Therefore, the time required to complete the combustion of all the uranium metal in a waste package is approximately 18 years (47,378 moles uranium ÷ 2,610 moles O_2 per year) assuming the oxidation of one mole of uranium consumes one mole of O_2 to form UO_2. The corresponding heat generation is 2,610 moles/yr × 1,084.9 kJ/mol = 2.8×10^6 kJ/yr, which is equivalent to about 90 watts). This assumes that the pyrophoric reaction is self sustaining (i.e., that the heat energy is dissipated slowly enough from the reaction sites that the pyrophoric reaction continues and is limited only by the rate of oxygen supply). If it is assumed that U_3O_8 is the oxidation product (heat of formation on the basis of one uranium = 1,191.6 kJ/mol (Grenthe et al. 1992 [DIRS 101671], Section v.3.3.3.1)), then the oxidation of the fuel in the waste package occurs with a corresponding heat generation rate of approximately 74 watts.

As discussed above, the oxidation of the uranium metal fuel will not adversely affect radionuclide release because the TSPA model uses a bounding instantaneous degradation rate for DOE SNF other than naval SNF (BSC 2004 [DIRS 172453], Section 8.1). Because the heat output rate is small compared to the initial decay heat generation rates (SNL 2007 [DIRS 180472], Table 7-5[a]), the associated increase in the overall waste package temperature is expected to be small (see corroborating evidence below) and would therefore not lead to further degradation of the waste package outer shell that might increase the rate of oxygen ingress. Also, the small temperature increases involved are not expected to melt or otherwise degrade the codisposed glass waste.

<u>Oxygen Ingress by Barometric Pumping:</u> Barometric pressure fluctuations at the surface are transmitted to the repository horizon with some amplitude attenuation (BSC 2004 [DIRS 169734], Section 7.3.2). Pressure measurements made prior to excavation of the ESF indicated that the attenuated amplitude of the pressure fluctuations are less than 1% (BSC 2004 [DIRS 169734], Figure 7-27). For this analysis of oxygen ingress into a breached waste package due to barometric pressure fluctuations in the repository, it is conservatively assumed that the pressure fluctuations occur with a diurnal (twice daily) rhythm each involving a fluctuation of about 1%. Assuming that the pressures inside and outside the waste package are equilibrated in each of the twice-daily pressure fluctuations, the fractional rate at which the gasses in the void space of a breached waste are replaced by outside air is given by 1% × 2 per day = 2% per day. The void volume of the codisposal waste packages containing two MCOs packages is 5,700 ~~7,400~~ liters (DTN: SN0702PAIPC1CA.001 [DIRS 186224 ~~180451~~], spreadsheet: *CDSP-2MCO Cell 1.xls*, sheet: "WP Cell 1 Moles & Surf Areas," cell G12 ~~G11~~). Given that the mole fraction of oxygen in air is 0.20946 (Weast 1984 [DIRS 106170], p. F-162), the moles of oxygen ingress into a breached waste package as a result of barometric pumping can be calculated as: 5,700 ~~7,400~~ liters × 0.02 × 365 days per year/22.4 liters per mole × 0.20946 (oxygen mole fraction in air) = ~~505~~ 389 moles oxygen per year.

This is a relatively small rate of oxygen ingress compared to that calculated above for diffusion through SCCs. Hence, the effects of this source of oxygen ingress are small compared to those discussed above for oxygen ingress due to diffusion.

Table 2.1.02.08.0A-1. Direct Inputs (Continued)

Input	Source	Description
DTN: SN0702PAIPC1CA.001. In-Package Chemistry Calculations and Abstractions. [DIRS ~~180451~~ 186224]	file: *CDSP-2MCO Cell 1.xls*, worksheet: "WP Cell 1 Moles & Surf Areas," cell: ~~G11~~ G12	The total void volume of the co-disposal waste packages containing two MCOs packages is ~~7,400~~ 5,700 liters
Garvin 2002. *Multi-Canister Overpack Topical Report*. [DIRS 169141]	Table 4-4	The estimated acceptable amount of water in a sealed MCO is 4.64 kg (bound in particulate), with less than 200 g being present as free water
	Section 4.1.3.2	MCOs will be dried and filled with helium
	Table 4-4	1.1 × 10^7 g uranium metal per waste package, assuming that the waste package contains two MCOs and each MCO contains Mark IV fuel (3,804 kg U) and scrap (1,832 kg U) for a total of 5,636 kg U
Grenthe et al. 1992. *Chemical Thermodynamics of Uranium*. [DIRS 101671]	Table III.1 and Sections v.3.3.3.1 and v.1.1	Heats of formation of UO_2 and U_3O_8. Specific heat capacity of uranium metal
Lide 2000. *CRC Handbook of Chemistry and Physics*. [DIRS 162229]	p. 1-8	Molar volume of an ideal gas at standard temperature and pressure
SNL 2007. *Seismic Consequence Abstraction*. [DIRS 176828]	Table 6-18	Estimates of the conditional damaged areas for the 23-mm-thick OCB with intact internals
	Table 6-3	1.05 m/s corresponds to an exceedance frequency of 10^{-5} per year on the bounded hazard curve
SNL ~~2008~~ 2007. *EBS Radionuclide Transport Abstraction*. [DIRS 177407]	Section 6.6.2	Approach for calculating diffusive mass transport rate of gasses through stress corrosion cracks in the waste package outer barrier. Number of stress corrosion cracks and the associated diffusion area. Including molar density of ideal gas (37.712 mol/m^3), and diffusion coefficient for O_2 in air (2.37 × 10^{-5} m^2/s)
SNL 2007. *Stress Corrosion Cracking of Waste Package Outer Barrier and Drip Shield Materials*. [DIRS 181953]	Table 8-13	Bounding estimate of the stress corrosion cracking area density following a seismic event
SNL 2007. *Total System Performance Assessment Data Input Package for Requirements Analysis for DOE SNF/HLW and Navy SNF Waste Package Overpack Physical Attributes Basis for Performance Assessment*. [DIRS 179567]	Table 4-10	Mass of steel per waste package (unloaded)
SNL 2007. *Total System Performance Assessment Data Input Package for Requirements Analysis for TAD Canister and Related Waste Package Overpack Physical Attributes Basis for Performance Assessment*. [DIRS 179394]	Table 4-3	Waste package outer barrier wall thickness
SNL 2008. *Screening Analysis of Criticality Features, Events, and Processes for License Application*. [DIRS 173869]	Appendix I	Waste package is dried and filled with helium
Weast 1984. *CRC Handbook of Chemistry and Physics*. [DIRS 106170]	p. F-162	Mole fraction of oxygen in air

FEP: 2.1.03.04.0A

FEP NAME:

Hydride Cracking of Waste Packages

FEP DESCRIPTION:

The uptake of hydrogen and the formation of metal hydrides may mechanically weaken the waste packages and promote degradation.

SCREENING DECISION:

Excluded – low probability

SCREENING JUSTIFICATION:

Hydrogen generated at cathodic sites on a corroding metal may be absorbed into the metal and, if present at a sufficiently high concentration, could degrade the mechanical properties and potentially increase the metal's susceptibility to crack initiation and/or propagation. The hydrogen concentration achieved within a material is a direct function of the rate at which atomic hydrogen is generated at the metal surface (e.g., the rate of the water reduction reaction on a corroding metal), which in turn defines the surface coverage of adsorbed hydrogen. The subsurface absorbed hydrogen concentration (i.e., atomic hydrogen dissolved in the metal matrix at the metal surface) achieved is determined by this surface coverage combined with the efficiency through which it is absorbed into the metal. Once hydrogen has been absorbed into the metal, it will then migrate further into the material via diffusional processes. This migration will continue until there is no longer a chemical potential gradient to drive diffusion (i.e., the bulk hydrogen concentration is equivalent to the subsurface hydrogen concentration). The term hydrogen embrittlement is used to refer to the deleterious impact of hydrogen on the mechanical properties of a material. Hydrogen-induced cracking results from the combined action of absorbed hydrogen and residual or sustained applied tensile stresses, whereby crack initiation and/or propagation occurs at lower stress levels than in the absence of absorbed hydrogen. In the case of nickel-based alloys such as Alloy 22, hydrogen embrittlement typically manifests as a reduction in fracture toughness or an overall loss of ductility (ASM International 1987 [DIRS 103753], pp. 650 to 652). It should be noted that solid solution strengthened nickel-based alloys such as Alloy 22 do not form a hydride phase.

The Alloy 22 waste package, when emplaced, is protected by the drip shield. The drip shield will prevent any fallen ground support from contacting the waste package, thereby eliminating the chances of galvanic coupling. Likewise, the pallet will keep the waste package from contacting the invert (SNL 2007 [DIRS 179354], Table 4-3, Parameter Number 08-03), thereby precluding the galvanic coupling between the waste package and any material (such as carbon steel) in the invert. However, in the event that either the drip shield or the pallet fail to prevent electrical isolation of the waste package from the metals in the support structure or invert, hydrogen-induced cracking of Alloy 22 will still not take place due to the properties discussed in the following text. Hydrogen-induced cracking of the internal stainless steel components will not occur prior to waste package breach due to the insignificant degree of corrosion (excluded

for the nominal scenario case (i.e. not seismic or igneous),

(e.g., after the repository is disrupted by a seismic or igneous event) evaluation led to the conclusion that, even at 400°C, the reaction rate is "so small as to be of no practical consequence." Therefore, oxidation of the carbide-bearing SNF upon waste package breach is not anticipated to be a concern (Propp 1998 [DIRS 149395], Summary), and should not be a significant source for gas generation within the waste package.

- Decay-derived helium may be released from the DOE SNF within codisposal waste packages. However, the codisposal waste packages containing two MCOs and DOE SNF have a much smaller inventory of the radionuclides that can produce decay-derived helium in comparison to the commercial SNF waste packages (SNL 2007 [DIRS 180472], Table 7-1[a]). It follows that the potential pressurization effects of decay-derived helium on the codisposal waste packages are bounded by the internal pressurization of the commercial SNF in a TAD canister-bearing waste package, and can therefore be excluded based on the low consequence justification given above.

- The maximum pressure inside an MCO in the absence of a hydrogen deflagration has been estimated in excluded FEP 2.1.13.01.0A (Radiolysis). This analysis is based on the maximum amount of free and bound (hydrated) water that has been reported for all MCOs loaded to date. The pressure from release of all bound water and from prepressurization with 1.5 atm of helium gas is estimated to be 38 atmospheres (559 psia) at 211°C, the maximum value for the peak waste package temperature (SNL 2008 [DIRS 184433], Table 6.3-49[a]). This pressure is well beyond the design pressure for the MCO, 450 psig at 132°C (Garvin 2002 [DIRS 169141], Section 2.2.6.2). If both ~~an~~ MCO s fail~~s~~ from overpressurization, they ~~it~~ will vent into the void volume inside the codisposal waste package. The resulting pressure is at most 84 ~~104~~ psia at 211°C (see excluded FEP 2.1.13.01.0A (Radiolysis)), which is less than the design pressure of the waste package, 140 psia at 707°F (375°C) (BSC 2007 [DIRS 180190], Appendix B, B4.2.2).

  The maximum pressure in the event of a hydrogen deflagration is also analyzed in excluded FEP 2.1.13.01.0A (Radiolysis). The maximum pressure from a hydrogen deflagration is estimated to be about 16 atmospheres, or 235 psia, well below the MCO design pressure of 450 psig at 132°C (Garvin 2002 [DIRS 169141], Section 2.2.6.2). If the MCO canister fails from the hydrogen deflagration, the pressure is vented into the larger void volume inside the codisposal waste package, further reducing the pressure.

- The effects of radiolysis on the free water that remains inside an MCO and on the water that is bound in hydrides on the N reactor fuel in the MCO are analyzed in excluded FEP 2.1.13.01.0A (Radiolysis). The effects of radiolysis on the free and bound water are reflected in the predicted gas pressure inside an MCO in the absence of a hydrogen deflagration and in the event of a hydrogen deflagration, as discussed earlier.

In summary, the pressure increases within an MCO should be within the design pressure for the MCO or within the design pressure for the codisposal waste package containing the MCOs. The processes leading to internal pressurization of the codisposal waste package with two MCOs and DOE SNF can be excluded based on low consequence.

FEP: 2.1.06.05.0C

FEP NAME:

Chemical Degradation of Emplacement Pallet

FEP DESCRIPTION:

Degradation of the materials used in the pallet supporting the waste package may occur by chemical or microbial processes, and may affect the long-term performance of the repository.

SCREENING DECISION:

Included

TSPA DISPOSITION:

Mechanical degradation of the emplacement pallet is discussed in excluded FEP 2.1.06.05.0A (Mechanical Degradation of Emplacement Pallet). In addition, microbial activity in the EBS is of low consequence with respect to potential chemical degradation of EBS components, including emplacement pallets (see excluded FEP 2.1.10.01.0A (Microbial Activity in EBS)). Chemical degradation of the emplacement pallet is included by performing structural analyses with thinned emplacement pallet components.

The waste package emplacement pallet supports the waste package during handling, emplacement, preclosure, and postclosure periods. In the first 10,000 years after emplacement, in the absence of seismic or igneous activity, the emplacement pallet maintains a waste package in a nominally horizontal position (SNL 2007 [DIRS 179354], Table 4-3, Parameter Number 08-02). The emplacement pallet waste package supports are fabricated from Alloy 22 and the emplacement pallet connector tubes are fabricated from Stainless Steel Type 316 (SNL 2007 [DIRS 179354], Table 4-3, Parameter Number 08-01). The stainless steel tubes connect to the Alloy 22 waste package supports. Galvanic coupling between Alloy 22 and Stainless Steel Type 316 is discussed in excluded FEP 2.1.09.09.0A (Electrochemical Effects in EBS).

for the nominal scenario case

The Alloy 22 emplacement pallet supports are the main load-bearing members because the geometry of the emplacement pallet prevents direct contact between the waste package and non-Alloy 22 drift components (SNL 2007 [DIRS 179354], Table 4-3, Parameter Number 08-03). The emplacement pallet is designed with margins accounting for corrosion such that it meets the requirements to support the waste package (SNL 2007 [DIRS 179354], Table 4-3, Parameter Number 08-03) during the first 10,000 years after closure. The corrosion allowance for both the Alloy 22 and stainless steel components shall be at least 2 mm (SNL 2007 [DIRS 179354], Table 4-3, Parameter Number 08-03). As discussed below, the corrosion of the connector tubes over the first 10,000 years after closure is low enough that the connector tubes retain their structural integrity. The structural integrity of the connector tubes is only important in the case of a seismic event of sufficient acceleration to cause the waste package to separate from the emplacement pallet.

for the nominal scenario case (i.e. not seismic or igneous)

FEP: 2.1.06.07.0A

FEP NAME:

Chemical Effects at EBS Component Interfaces

FEP DESCRIPTION:

Chemical effects that occur at the interfaces between materials in the drift may affect the performance of the system.

SCREENING DECISION:

Excluded – low consequence

SCREENING JUSTIFICATION:

The EBS component interfaces addressed in this FEP are those that may involve solid-solid interactions. Solid–liquid interactions of EBS components are addressed in included FEPs 2.1.03.01.0A (General Corrosion of Waste Packages) and 2.1.03.03.0A (Localized Corrosion of Waste Package) for general and localized corrosion of the waste package, respectively. In addition, included FEP 2.1.03.01.0B (General Corrosion of Drip Shields) and excluded FEP 2.1.03.03.0B (Localized Corrosion of Drip Shields) address general and localized corrosion of the drip shield, respectively. As described in *Total System Performance Assessment Data Input Package for Requirements Analysis for Engineered Barrier System In-Drift Configuration* (SNL 2007 [DIRS 179354]), the base plates of the drip shield are fabricated from Alloy 22 (SNL 2007 [DIRS 181339], Section 6.3) to prevent direct contact between the titanium and steel members in the invert, thus minimizing electrochemical effects at this interface (SNL 2007 [DIRS 179354], Table 4-2, Parameter Number 07-07). This configuration prevents contact between the titanium and invert steel, to avoid hydrogen diffusion into the titanium (SNL 2007 [DIRS 181339], Section 6.3). The pallet pedestals are fabricated of Alloy 22, as is the waste package outer shell (SNL 2007 [DIRS 179354], Table 4-3, Parameter Numbers 08-01 and 08-03), thus precluding galvanic reactions at this interface. It should be noted that the pallet connector rods are made of stainless steel and will be in contact with the Alloy 22 pallet pedestals. If galvanic corrosion occurs, it will attack the invert steel rather than the Alloy 22 in the pallet pedestal because of the former's lower resistance to corrosion. Further discussions on the potential effects of galvanic interactions between EBS components are given in excluded FEP 2.1.09.09.0A (Electrochemical Effects in EBS). This FEP also concludes that enhanced degradation as a result of galvanic interactions would be negligible due to similarities in the corrosion potentials of the considered metals and alloys in the EBS that may come into contact with one another.

for the nominal scenario case
(i.e. not seismic or igneous)

Interactions between various types of EBS components as a result of extensive degradation and subsequent consolidation of these assemblies is discussed in excluded FEP 2.1.08.15.0A (Consolidation of EBS Components). The only exception is the case of drift collapse as a result of seismically induced ground motion. In this case, rockfall could damage the drip shield and possibly the outer shells of the waste packages (assuming drip shield failure) as discussed in included FEP 1.2.03.02.0C (Seismic-induced Drift Collapse Damages EBS Components).

FEP: 2.1.07.05.0B

FEP NAME:

Creep of Metallic Materials in the Drip Shield

FEP DESCRIPTION:

Metals used in the drip shield may deform by creep processes in response to deviatoric stress.

SCREENING DECISION:

Excluded – low consequence

SCREENING JUSTIFICATION:

The drip shield can be subjected to plastic deformation and mechanical damage due to stresses resulting from static and dynamic load resulting from rockfall or from vibratory ground motion.

dependent. Due to the long duration of the regulatory period and the possibility of early drift collapse after the waste emplacement, it is important to analyze time-dependent deformation and the stability of the drip shield when non-uniformly loaded by the rock rubble mass.

The hottest waste package temperature in an open drift remains below 150° C for over 98% of the 10,000 years following closure of the repository (SNL 2008 [DIRS 184433], Figure 6.3-76[a]). Due to greater distance of the drip shield from the heat source (i.e., the waste form) than the waste package, surface temperatures of the drip shield will be lower than those for the waste packages. For the waste package surface to exceed 300° C, a seismic event of sufficient magnitude must occur within approximately 90 years after closure, result in a drift collapse, and affect a waste package with an unfavorable combination of a high thermal output surrounded by a low conductivity rubble (SNL 2008 [DIRS 179962], Section 6.5.1). However, even if such a scenario were to take place, the hottest waste package temperature will still be below 150° C for approximately 94% of the 10,000 years following closure of the repository (SNL 2008 [DIRS 184433], Figure 6.3-82[a]).

Plastic deformation and mechanical damage of the drip shield are expected to be enhanced at elevated temperatures due to the combined effect of thermal and mechanical stresses. ~~Without drift collapse, the waste package temperature will be below 300°C (SNL 2008 [DIRS 184433], Figure 6.3-76[a]). Due to greater distance of the drip shield from the heat source (i.e., the waste form) than the waste package, surface temperatures of the drip shields will be lower than those for the waste packages. For the waste package surface to exceed 300°C, a seismic event of sufficient magnitude must occur within approximately 90 years after closure, result in drift collapse, and affect a waste package with an unfavorable combination of a high thermal output surrounded by a low conductivity rubble (SNL 2008 [DIRS 179962], Section 6.5.1).~~ Analyses have shown that the mean probability of these conditions occurring is about one in 10,000 within the first 10,000 years after closure (SNL 2008 [DIRS 179962], Section 6.5.1). Therefore, a reasonably bounding drip shield exposure temperature in the repository is ~~300~~°C and is used in the analysis of creep of metallic materials in the drip shield.

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A review of scientific literature (Dutton 1995 [DIRS 173919], p. 8; Dutton 1996 [DIRS 174750], Section 2) reveals that Titanium Grades 7 and 29 can undergo creep deformation at temperatures as low as room temperature when subject to tensile stresses exceeding approximately 50% of the yield strength. Therefore, one of the important impediments to drip shield performance during the period of 10,000 years after closure is potential creep deformation under long-term applied loads. With the exception of the stresses imposed on the drip shield due to its own weight the maximum resultant total creep strains remain below 5% during the 10,000-year period analyzed (BSC 2005 [DIRS 174715], Section 5.6). The maximum creep strains occur in the plates; the maximum creep strain in the support beams and the bulkheads are significantly less than that observed for the plate. These relatively low long-term strain levels, which are much less than the creep strains expected for the onset of tertiary creep, indicate that while some creep deformation may occur, it does not impact the drip shield seepage diversion function or the ability of the drip shield to protect the waste package from load (static or dynamic) by the rock overburden mass.

Based on the relatively low, structurally acceptable creep strains calculated for loading conditions more severe than those anticipated within Yucca Mountain both pre- and postclosure (BSC 2005 [DIRS 174715]), and the lack of potential resultant effects on dose, the effect of creep on the drip shield is negligible.

Based on the previous discussion, omission of FEP 2.1.07.05.0B (Creep of Metallic Materials in the Drip Shield) will not result in a significant adverse change in the magnitude or timing of either radiological exposure to the RMEI or radionuclide releases to the accessible environment. Therefore, this FEP is excluded from the performance assessments conducted to demonstrate compliance with proposed 10 CFR 63.311 and 63.321 (70 FR 53313 [DIRS 178394]), and with 10 CFR 63.331 [DIRS 180319], on the basis of low consequence.

INPUTS:

Table 2.1.07.05.0B-1. Direct Inputs

Input	Source	Description
BSC 2004. *Mechanical Assessment of the Drip Shield Subject to Vibratory Ground Motion and Dynamic and Static Rock Loading*. [DIRS 169753]	Section 5.4.3.2	Calculation of initial loads on drip shield
BSC 2005. *Creep Deformation of the Drip Shield*. [DIRS 174715]	Section 5.6	Anaysis of drip shield creep
SNL 2008. *Multiscale Thermohydrologic Model*. [DIRS 184433]	Figure 6.3-76[a]	~~Maximum waste package surface temperature will be less than 300°C~~

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Figure 6.3-82[a]

Hottest waste package temperature in an open drift is below 150° C for over 98% of the 10,000 years following closure.
Hottest waste package temperature in a collapsed drift is below 150° C for approximately 94% of the 10,000 years following closure.

Number 07-07), which is attached to the bottom of the drip shields. The Alloy 22 drip shield base is in contact with the invert.

A commercial SNF TAD canister will be placed inside the double-walled waste package. The design characteristics used in modeling the TAD canister-bearing waste packages are documented in *Total System Performance Assessment (TSPA) Data Input Package for Requirements Analysis for TAD Canister and Related Waste Package Overpack Physical Attributes Basis for Performance Assessment* (SNL 2007 [DIRS 179394]). The TAD canister vessel and structural internals (i.e., basket) shall be constructed of 300-series stainless steel (such as UNS S31603, which may also be designated as Stainless Steel Type 316L).

The main codisposal waste package (N Reactor) components use the following materials: Alloy 22 for the outer corrosion barrier, Stainless Steel Type 316 for the inner vessel, Carbon Steel Type A516 for the divider plate fuel support plate assemblies, Stainless Steel Type 304L for the MCO and glass pour canisters , and Aluminum Alloy Type 1100 for the MCO spacer (SNL 2007 [DIRS 180506], Sections 4.1.4 and 4.1.4[a]).

for the nominal scenario case (i.e. not seismic or igneous),

In the 10,000 years following repository closure, ~~the~~ waste package emplacement pallet prevents direct contact of the waste package with the invert (SNL 2007 [DIRS 179354], Table 4-3, Parameter Number 08-02). The Alloy 22 waste package supports are the main load-bearing members because the geometry of the pallet and waste package supports prevents direct contact between the waste package and the emplacement pallet tubes (SNL 2007 [DIRS 179354], Table 4-3, Parameter Number 08-03). The emplacement pallet keeps the waste package from contacting other dissimilar metals in the absence of seismic activity (SNL 2007 [DIRS 179354], Table 4-3, Parameter Number 08-03). The affects of seismic activity on mechanical degradation of EBS components is addressed in included FEPs 1.2.03.02.0A (Seismic Ground Motion Damages EBS Components) and 1.2.03.02.0C (Seismic-induced Drift Collapse Damages EBS Components), and excluded FEP 1.2.03.02.0B (Seismic-induced Rockfall Damages EBS Components).

The carbon steel invert structure will provide a framework, consisting of a series of beams bolted to the invert rock mass, that supports the emplacement pallets, waste packages, and drip shields (SNL 2007 [DIRS 179354], Table 4-1, Parameter Number 02-08). The base plates of the drip shield are fabricated from Alloy 22 to prevent direct contact between the titanium and steel members in the invert, thus minimizing electrochemical effects at this interface (SNL 2007 [DIRS 179354], Table 4-2, Parameter Number 07-07). The corrosion resistance of the Alloy 22 WPOB, emplacement pallet components, and base plates of the drip shield, as well as the titanium drip shield components, is much greater than the carbon steel and, to a lesser extent, the stainless steel invert components. If any electrical contact were to be established between these Alloy 22 or titanium components and the invert materials, the invert materials would corrode preferentially. The potential for corrosion-generated hydrogen to embrittle the waste package or drip shield is discussed in excluded FEPs 2.1.03.04.0A (Hydride Cracking of Waste Packages) and 2.1.03.04.0B (Hydride Cracking of Drip Shields), respectively. If the invert components completely degrade before such electrical contacts were possible, no galvanic effects would occur.

over-pressurization of the waste package is rupture and possible damage to one (or possibly two) neighboring waste packages.

Excluded FEPs that calculate pressure effects (e.g., FEPs 2.1.03.07.0A (Mechanical Impact on Waste Package) and 2.1.12.02.0A (Gas Generation (He) From Waste Form Decay)) use a TAD canister void volume of 4,737 L (from DTN: SN0702PAIPC1.001 CA [DIRS ~~180451~~ 186224], file: *CSNF WP* TAD *Design Cell 1.xls*, worksheet: "TAD WP Total Moles and SA," cell: B48). This volume is based on a chemical "cell" inside a TAD canister-bearing waste package (*cell 1* intended for in-package chemical calculations), and does not correspond to a physically defined volume that is potentially larger by as much as 70% (see SNL 2007 [DIRS 177407], Section 6.3.4.3.4.2, p. 6-90). There is uncertainty in estimating pressures inside a TAD canister-bearing waste package. Nevertheless, in order to help maintain consistency among FEPs, so that pressure calculations might be compared more directly, the in-package chemistry "cell 1" TAD canister void volume of 4,737 L (DTN: SN0702PAIPC1.001 CA [DIRS ~~180451~~ 186224]) is used in this FEP to estimate pressure inside a TAD canister-bearing waste package. All calculations of pressure performed in this document were conducted in units of atm and converted to psia according to 1 atm = 14.7 psia. No attempt was made to convert the resulting pressure in atm to psig (gauge pressure), although some specifications may be given in this unit (notably, the design pressure for an MCO canister from Garvin 2002 [DIRS 169141], Section 2.2.6.2). Because gauge pressure (psig) is less than or equal to absolute (psia), there is approximately a 1 atm (or less) margin of error in all calculated values when compared to psig (where applicable), such that the effect of this uncertainty on conclusions reached in this document is negligible.

The potential for over-pressurization and rupture of a TAD canister-bearing (commercial SNF) waste package due to waste package pressurization by several relevant processes (including gas generation by radiolysis) is addressed in excluded FEP 2.1.03.07.0A (Mechanical Impact on Waste Package). This FEP concludes that, even considering the upper limit of expected waste package temperatures (approximately 350°C for the drift-collapse case), rupture of a waste package due to over-pressurization is not expected to be a concern before 10,000 years after closure (pressure at 350°C is approximately 114 psia, from excluded FEP 2.1.03.07.0A (Mechanical Impact on Waste Package)). The safety margin is such that, in the absence of water or gases generated by radiolytic decomposition of water, the maximum expected pressure achievable inside a TAD canister-bearing (commercial SNF) waste package is on the order of 114 psia (0.8 MPa) at 350°C, whereas the design pressure for a commercial SNF waste package is 140 psia (0.97 MPa) at 375°C (SNL 2007 [DIRS 179394], Section 4.1.2.6; note that the temperature specified is 707°F rather than 375°C). In fact, a more reasonable maximum pressure – at 200°C – is not expected to exceed 70 psia (0.47 MPa), about one-half the design pressure.

According to *Total System Performance Assessment Data Input Package for Requirements Analysis for Transportation Aging and Disposal Canister and Related Waste Package Physical Attributes Basis for Performance Assessment* (SNL 2007 [DIRS 179394], Table 4-1, Parameter Number 04-04), "all TAD canisters and waste packages shall be dried and backfilled with Helium [sic] to achieve less than 0.43 mole (7.7 g) of H_2O in a 7 m^3 TAD canister after drying in a manner similar to *Standard Review Plan for Dry Cask Storage Systems* (NRC 1997 [DIRS 101903], Section 8.V.1)." The value of 0.43 mole in 7 m^3 is taken from Knoll and Gilbert (1987 [DIRS 123682] Table 3, p. 12), refers to the amount of H_2O in the gas phase only. The procedure described in NUREG-1567, *Standard Review Plan for Spent Fuel Dry Storage*

Facilities (NRC 2007 [DIRS 149756], Section 9.5.4.1) cites NUREG-1536 (NRC 1997 [DIRS 101903], Section 8.V.1) for moisture removal and is therefore acceptable. It is expected that compliance with this requirement will be accomplished according to specifications, and that there is no need to evaluate the potential for failing to meet that requirement, consistent with excluded FEP 1.1.08.00.0A (Inadequate Quality Control and Deviations from Design).

As discussed in excluded FEP 2.1.03.07.0A (Mechanical Impact on Waste Package), the complete conversion of 0.43 moles of water to 0.65 moles of H_2 and O_2 gas results in a pressure increase of only about 0.08 psia at 211°C (the temperature of the analysis). Water in the gas phase does not preclude (and in fact implies) some small quantity of adsorbed and potentially chemically bound water inside a properly dried and inerted TAD canister. To this vapor-phase water must be added any additional pressure that might be achieved if all adsorbed and chemically bound water (if present) were to also be converted to H_2 and O_2 gas. However, because the amount of water in the vapor phase is so small, only a few monolayers of water is expected to be adsorbed (e.g., less than about 10 to 15 nm). Spread over the approximately 1,200 m^2 surface area inside a 21-PWR waste package (SNL 2007 [DIRS 177407], Table 6.3-10) means that, at most, about one mole of additional water needs to be accounted for. Converting this to 1.5 moles of gas by radiolysis increases the pressure inside a TAD canister by only about 0.6% (0.2 psia). Thus, a reasonable assumption is that the potential pressure increase due to complete radiolytic conversion of water into gas might increase in-package pressure by less than one percent (at 211°C), so that the maximum expected pressure will still be approximately one-half the design pressure. The potential conservatism of this calculation should also be emphasized because, due to the high reactivity of radicals generated by radiolysis (many of which must recombine, rather than react with solids, in order to produce molecular O_2), it is highly doubtful that it will be possible to completely convert water into gas at a ratio of 1:1.5. Nevertheless, even if all water is converted into gas at a ratio of 1:1.5, the net effect on pressurizing a TAD canister-bearing waste package can be excluded on the basis of low consequence.

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$\{24.5+358 \text{ mol}\} \times \{0.082\ \text{L·atm·mol}^{-1}\text{·K}^{-1}\} \times \{484.15 \text{ K}\} \div [400 \text{ L}] =$

The maximum pressure that could be generated inside an MCO in the absence of a hydrogen fire can be estimated by assuming that one MCO in a codisposal waste package contains the maximum amount of free and bound water, as reported for all MCOs loaded to date: 4.3 kg or 239 moles H_2O (Sexton 2007 [DIRS 184742], Table 2-1). If pressurized at 25°C to 1.5 atm (0.15 MPa or 22 psia) with helium (24.5 mole helium in 400 L void volume; DTN: SN0702PAIPC1CA.001 [DIRS ~~180451~~], file: *CDSP – 2MCO Cell 1.xls*, worksheet: "Void Space," cell C51) and assuming all residual water is converted into H_2 and O_2 gas (358 mole gas = 1.5 × 239 mole H_2O) the design pressure of 450 psi (at 132°C; Garvin 2002 [DIRS 169141], Section 2.2.6.2) will be exceeded at about 117°C for a single MCO. The pressure inside the MCO at 211°C would reach 559 psia~~)~~ (38 atm = ~~3.8 MPa~~), well beyond the design pressure. Therefore, it can be expected that an MCO containing the maximum amount of water will fail due to over-pressurization.

559 psia

Failure of an over-pressurized MCO canister is not expected to damage the inner stainless-steel liner (two inches thick) and outer corrosion barrier (one inch thick) sufficiently to diminish the overall pressure rating of the codisposal waste package (140 psia; SNL 2007 [DIRS 179394], Section 4.1.2.6). Rather, a failed MCO is expected to vent into the surrounding codisposal waste package, which has a net void volume of ~~3,000~~ L (~~7,400~~ L minus the ~~net volumes~~ of two MCO

4,600

void spaces

5,700

total void space

282

"WP Cell 1 Moles & Surf Areas", cell: G12 and

400

, cells C51 and C16 respectively

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150

4,600

s

5,000

4,600

600

78

78 psia

canisters at ~~1,000~~ L each and two HLW glass canisters at ~~1,200~~ L each; volumes from DTN: SN0702PAIPC1CA.001 [DIRS ~~180451~~], file: *CDSP – 2MCO Cell 1.xls*, worksheet: "Void Space"). It is assumed further here that the codisposal waste package will have also been pressurized to 1.5 atm with helium at 25°C (~~184~~ mole helium in ~~3,000~~ L of void volume). Combining the void volumes of the codisposal waste package and one MCO canister (~~3,000~~ + 400 = ~~3,400~~ L) indicates that the design pressure for the waste package will not be exceeded for temperatures below about ~~425~~°C, and that the pressure at 211°C would only be about ~~93~~ psia (~~6.3~~ atm = ~~0.64 MPa~~). Including the void volumes for both MCOs in the calculation increases the attainable pressure by only about ~~7% (e.g., 104 psia (7.1 atm = 0.71 MPa) at 211°C)~~ if one MCO canister is assumed to contain the maximum amount of water (4.3 kg) and the second MCO canister is assumed to contain the average value of 1.03 kg (57 moles) total water (Sexton 2007 [DIRS 184742], Table 2-1). It should be noted that an MCO with only an average mass of water (1.03 kg; Sexton 2007 [DIRS 184742], Table 2-1) will not exceed its design pressure of 450 psig below about 1,000°C, so that the preceding calculation might tacitly assume damage to the second MCO canister caused by failure of the first.

8 % to 84 psia ({24.5+85.5+664.5 mol} x {0.082 $\mathrm{L\cdot atm\cdot mol^{-1}\cdot K^{-1}}$} x {484.15 K} ÷ [5400 L] = 5.7 atm = 84 psia)

The minimum hydrogen concentration that can support flammability varies, depending on the major constituents of the gaseous environment. A minimum hydrogen concentration of approximately 4 vol % in an air-hydrogen atmosphere at nominal (0.1 MPa) pressure is required to propagate a flame front (Coward and Jones 1952 [DIRS 182138], Figure 7). For a helium-hydrogen environment, the minimum hydrogen concentration that can support flammability is approximately 8 vol % (Coward and Jones 1952 [DIRS 182138], Table 3). A reasonably conservative estimate of the maximum concentration of hydrogen gas that could be generated inside a TAD canister due to radiolysis can be calculated by assuming that a TAD canister that has been dried according to procedure (no more than 0.43 moles H_2O in 7 m^3 volume of cover gas) has an estimated one mole of water that remains sorbed or chemically bound inside the TAD canister after backfilling with helium to 1.5 atm and sealing (moles of helium given by the ideal gas law: $n = PV/RT = \{1.5 \text{ atm} \times 4{,}737 \text{ L}\} \div \{0.082 \text{ L}\cdot\text{atm}\cdot\text{mol}^{-1}\text{ K}^{-1} \times 298.15 \text{ K}\} = 291$ mole-helium). It is further assumed that all water inside the TAD canister (0.43 mole + 1 mole ≅ 1.5 moles H_2O = 27 grams H_2O) is converted to hydrogen and oxygen gas by radiolysis. Such a calculation demonstrates that, in the absence of any failure of the cladding, the maximum concentration of hydrogen is about one-half of one percent (0.005 ≅ 1.5 moles-H_2 ÷ [291 moles-He + 0.75 moles-O_2 + 1.5 moles-H_2]). Back-filling a TAD canister to 2 atm and potential rupture of cladding only reduces this concentration further, as does He generated due to alpha decay. Thus, as demonstrated by this bounding analysis, it is not possible to attain conditions capable of supporting a hydrogen fire inside a TAD canister-bearing waste package.

({282+382.5 mol} x {0.082 $\mathrm{L\cdot atm\cdot mol^{-1}\cdot K^{-1}}$} x {484.15 K} ÷ [5000 L] = 5.3

The average mass of residual water (free and bound) that has been determined to remain in an MCO after being dried and inerted is approximately 1.03 kg (57 moles H_2O) (Sexton 2007 [DIRS 184742], Table 2-1). Nearly all this water is present as chemically bound water in corrosion products (the most abundant corrosion product being aluminum hydroxide, $Al(OH)_3$, with lesser amounts of uranium oxy-hydroxides and aluminum and iron hydrates; Garvin 2002 [DIRS 169141], Table 4-4 and p. 4-30). This water could be released and converted to free hydrogen and oxygen due to thermal and/or radiolytic decomposition of these hydrated oxides. If free oxygen and hydrogen are produced inside an MCO, much of the oxygen may be scavenged by reaction with exposed uranium metal in the breached fuel because of the rapid kinetics of the uranium-metal/oxygen reactions (Haschke 1998 [DIRS 174075], Table 1), as well

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Table 2.1.13.01.0A-1. Direct Inputs (Continued)

CDSP

total

5,700

Input	Source	Description
DTN: MO0502ANLGAMR1.016. HLW Glass Degradation Model. [DIRS 172830]	Table 8-1	HLW glass density (2.7 g/cm^3) and volume (1.1 m^3 = π × [0.3 m]^2 × [3.9 m])
DTN: SN0702PAIPC1CA.001. In-Package Chemistry Calculations and Abstractions. [DIRS ~~180451~~]	file: *CDSP 2MCO Cell 1.xls*, worksheet: "~~Void Space~~"	The ~~TAD~~ canister void volume is ~~4,737~~ L
	file: *CDSP 2MCO Cell 1.xls*, worksheet: "Void Space," cell C51	The ~~TAD~~ canister void volume is ~~4,737~~ L
	file: *CSNF WP Design Cell 1.xls*, worksheet: "TAD WP Total Moles and SA," cell: B48	The TAD canister void volume is 4,737 L
Garvin 2002. *Multi-Canister Overpack Topical Report*. [DIRS 169141]	Table 4-4	443 kg zirconium cladding per MCO (Mark IV maximum fuel load without scrap basket)
	Table 4-4	6,340 kg uranium metal per MCO (Mark IV maximum fuel load without scrap basket)
	Table 4-4	443 kg zirconium cladding per MCO (Mark IV maximum fuel load without scrap basket)
	Table 4-4	6,340 kg uranium metal per MCO (Mark IV maximum fuel load without scrap basket)
Grenthe et al. 1992. *Chemical Thermodynamics of Uranium*. [DIRS 101671]	Table IV.1	285.83 kJ/mol is the standard enthalpy of formation of water
	Section V.1.1	The heat capacity of uranium metal is 0.11 J/g • °C
Lide 2006. *CRC Handbook of Chemistry and Physics*. [DIRS 178081]	p. 4-127	The heat capacity of zirconium metal is 0.278 J/g • °C
Morgenstern and Choppin 1999. "Kinetics of the Reduction of Pu(V)O_2^+ by Hydrogen Peroxide." [DIRS 184023]	pp. 109 to 111; Table 1	Reduction of Pu(V) to Pu(IV) in basic solutions having hydrogen peroxide (H_2O_2) concentrations on the order of 0.04 to 0.00001 moles per liter and pH 7.9 to 10.8.
NRC 1997. *Standard Review Plan for Dry Cask Storage Systems*. [DIRS 101903]	Section 8.V.1	Required procedures for vacuum drying of commercial spent fuel storage canisters
Plys and Duncan 1999. *FAI/99-14, Rev. 1, Hydrogen Combustion in an MCO During Interim Storage*. [DIRS 184687]	Figure 5-1, pp. 6 and 7	The maximum achievable temperatures and pressures (11 times the initial pressure) for a hydrogen fire in a mixture of oxygen (21%) and helium (79%) inside an MCO
Robie et al. 1979. *Thermodynamic Properties of Minerals and Related Substances at 298.15 K and 1 Bar (10^5 Pascals) Pressure and at Higher Temperatures*. [DIRS 107109]	p. 414	Analogue for borosilicate waste glass
Sexton 2007. *Particulate and Water in Multi-Canister Overpacks (OCRWM)*. [DIRS 184742]	Table 2-1	Maximum amount of free and bound water in an MCO is 4.3 kg
	Table 2-1	The average value of free and bound water in an MCO is 1.03 kg

MCO

"WP Cell 1 Moles & Surf Areas", Cell: G12

400

s

TAD

and C16

The glass pour canister void volume is 150 L

Evaluation of the neutron absorber material misload failure mechanism is an important consideration for the determination of the criticality potential of configurations. The probability that proper neutron absorber material is not used in the waste package (or waste form if integrally connected) or becomes separated from the fissile material must then be evaluated for configurations where absorber material is necessary for criticality control. Misloading of the waste forms is also an important consideration for the determination of the criticality potential of configurations of commercial SNF that require loading restrictions (i.e., specified loading curves). The probability that such waste forms are not loaded as required must then be evaluated.

improper performance of the neutron absorber

The neutron absorber misload event represents ~~the absence and/or loss of efficacy of the neutron absorber plates~~ due to fabrication-related errors (e.g., incorrect material installed during fabrication, absorber content ~~of plates~~ outside specified range). These types of events can only occur during fabrication and/or loading of a canister due to process or procedural errors and are similar to waste package and drip shield early failure mechanisms (SNL 2007 [DIRS 178765], Section 6.2). Errors in fabrication and operational processes are primarily due to human factors that are common to the various processes. Surrogate fabrication and operational processes with associated human factor errors have been evaluated in *Analysis of Mechanisms for Early Waste Package/Drip Shield Failure* (SNL 2007 [DIRS 178765]) and results are used for such initiating events for the waste package and drip shield early failure mechanisms. The surrogate processes are:

1. Improper performance of the neutron absorber ~~plates~~ represented as a material selection error in the waste package component fabrication processes (SNL 2007 [DIRS 178765], Section 6.3.2)

2. Failure of the waste package and canister drying/inerting process represented as an operational process error (SNL 2007 [DIRS 178765], Section 6.3.5)

3. Drip shield misplacement allowing the possibility of advective seepage flow directly on a waste package OCB (SNL 2007 [DIRS 178765], Section 6.4.4)

4. Fabrication flaws allowing increased susceptibility to SCCs (SNL 2007 [DIRS 178765], Section 6.3).

Waste package fabrication and operational process error probabilities have been obtained from DTNs: MO0701PASHIELD.000 [DIRS 180508] and MO0705EARLYEND.000 [DIRS 180946]. The probability values assigned to absorber plate misloads due to material selection errors, waste package and canister operational process failures, waste package SCC mitigation process failures, and the occurrence of OCB closure lid weld flaws for this analysis are listed in Table 2.1.14.15.0A-1. The operational process failures include the drying and inerting process and OCB outer lid weld stress mitigation process. These processes are conceptually similar since each requires operator actions and the human error failure rate from the OCB outer lid weld stress mitigation process is assigned to each one in Table 2.1.14.15.0A-1.

PWR TAD canister loading curve violation:

$\{1 - P_B\ (0; ((3.8 \times 10^{-5} \times 1.25 \times 10^{-3} + 1.13\ \times 10^{-4} + 4.36 \times 10^{-9} \times 1.0) \times$

$1.65 \times 10^{-7}), 4568)\} = 8.5 \times 10^{-8}$

PWR TAD canister absorber misload:

$\{1 - P_B\ (0; ((3.8 \times 10^{-5} \times 1.25 \times 10^{-3} + 1.13\ \times 10^{-4} + 4.36 \times 10^{-9} \times 1.0) \times$

$1.25 \times 10^{-7}), 4568)\} = 6.5 \times 10^{-8}$

44-BWR TAD canister absorber misload:

$\{1 - P_B\ (0; ((3.8 \times 10^{-5} \times 1.25 \times 10^{-3} + 1.13\ \times 10^{-4} + 4.36 \times 10^{-9} \times 1.0) \times$

$1.25 \times 10^{-7}), 2915)\} = 4.1 \times 10^{-8}$

plate

DOE SNF canister absorber misload (DOE1, DOE2, and DOE7):

$\{1 - P_B\ (0; ((3.8 \times 10^{-5} \times 1.25 \times 10^{-3} + 1.13\ \times 10^{-4} + 4.36 \times 10^{-9} \times 1.0) \times$

$1.25 \times 10^{-7}), 1223)\} = 1.7 \times 10^{-8}$

~~Thus, a conservative estimate for the probability of achieving a configuration with criticality potential in the repository due to the presence of weld flaws in the OCB closure lid or other early failure mechanisms, based on summing this set of events, including the DOE1, DOE2, and DOE7 contributions is 2.1 × 10^−7 for 10,000 years.~~ Since the events in the above evaluation are all associated with operations during the preclosure period, the probabilities are constant over the postclosure time period. ~~It should be noted that the other DOE criticality SNF groups do not pose a criticality concern because they do not need to rely on neutron absorber plates for criticality control. These evaluations are demonstrated in *DOE SNF Phase I and II Summary Report* (Radulescu et al. 2004 [DIRS 165482]), *Intact and Degraded Mode Criticality Calculations for the Codisposal of TMI-2 Spent Nuclear Fuel in a Waste Package* (BSC 2004 [DIRS 168935]), and *Intact and Degraded Mode Criticality Calculations for the Codisposal of ATR Spent Nuclear Fuel in a Waste Package* (BSC 2004 [DIRS 171926]).~~

Summary—As documented in *Screening Analysis of Criticality Features, Events, and Processes for License Application* (SNL 2008 [DIRS 173869]), the probability of criticality for the in-package location is much less than 1 chance in 10,000 of occurrence within 10,000 years after disposal. Accordingly, this FEP is excluded from the performance assessments conducted to demonstrate compliance with proposed 10 CFR 63.311 and 63.321 (70 FR 53313 [DIRS 178394]), and with 10 CFR 63.331 [DIRS 180319], on the basis of low probability.

In addition, as documented in *Screening Analysis of Criticality Features, Events, and Processes for License Application* (SNL 2008 [DIRS 173869]) the probability of criticality for all locations is less than 1 chance in 10,000 of occurrence within 10,000 years after disposal. The results documented in this analysis are applicable for all waste forms and waste package variants.

Evaluating the event sequences for DOE SNF accounting for the probability of neutron absorber shot misload for the DOE1 (MOX), DOE5 (U/Th Oxide), and DOE8 (U-Zr/U-Mo alloy) waste forms, the estimated canister misload probability for these waste forms is given by:

DOE SNF canister absorber shot misload (214 DOE1, DOE5, and DOE8 canisters, SNL 2008 [DIRS 173869], Section 6.3.2) :

$\{1\text{-}P_B\ (0; ((3.77 \times 10^{-5} \times 1.25 \times 10^{-3} + 1.13 \times 10^{-4} + 2.19 \times 10^{-9}\ \times 1.0\ ) \times 1.25 \times 10^{-7}), 214)\} = 3.0 \times 10^{-9}$.

Thus, a conservative estimate for the probability of achieving a configuration with criticality potential in the repository due to early failure initiating events, based on summing the results above, combining the DOE1 (absorber plate and shot error), DOE2, DOE5, DOE7, and DOE8 contributions is 2.1 x 10^{-7} for 10,000 years.

repository (which can be stated as the probability of having at least one such sequence occur) and is given by Equation 2.1.14.19.0A-2 with $k = 0$. For the case where $k = 0$ and λ is small, Equation 2.1.14.19.0A-2 can be approximated by λ. Then, the probability of at least one waste package configuration with criticality potential occurring in the repository is given by λ $(= N \times p)$.

Events in the various seismic vibratory scenarios requiring probability values for the calculation are listed as follows:

1. Probability of a seismic vibratory ground motion event
2. Probability of waste package OCB damage from effects of the ground motion
3. Probability of improper absorber material in a commercial SNF or DOE SNF canister
4. Probability of a loading curve violation for a 21-PWR TAD canister
5. Probability of drip shield failure.

Probability of Seismic vibratory ground motion event—For seismic events causing waste package-pallet impacts that can damage a commercial SNF waste package at the 90% residual stress level, the probability of damage is zero at a PGV value of 2.44 m/s (exceedance frequency of 4.518×10^{-7} per year). At a PGV value of 4.07 (exceedance frequency of 1×10^{-8} per year), the probability of impact damage is 0.118 (DTN: MO0703PASDSTAT.001 [DIRS 183148], file: *Kinematic Damage Abstraction 23-mm Intact.xls*, worksheet: "Probability of Damage"). Seismic events with the range of annual exceedance frequencies that can damage a TAD waste package are represented in the column labeled "PGV Value" in Table 2.1.14.19.0A-1. The probability of a seismic event is a random event in time following a Poisson distribution (SNL 2007 [DIRS 176828], Section 5.2), which increases linearly in log-time. Thus, the probabilities that one or more of these basic events occurs (i.e., one minus the probability that none occurs) is determined with Equation 2.1.14.19.0A-2 and the information provided in Table 2.1.14.19.0A-1.

Table 2.1.14.19.0A-1. Probability of Seismic Vibratory Ground Motion Events ~~Causing~~ with Potential to Cause Damage to TAD Canister-Bearing Waste Packages

PGV Value (m/s)	λ_1 (events/year)	λ_2 (events/year)	t_1 (years)	t_2 (years)	Probability
< 2.44	4.52×10^{-7}	NA	NA	NA	NA
2.44 - 4.07	1.0×10^{-8}	4.52×10^{-7}	10,000	0	4.41×10^{-3}

Source: DTN: MO0705CRITPROB.000 [DIRS ~~184958~~ 186328], file: *Fault Displacement Abstraction for Criticality Updated DTN 10-25-07.xls*, worksheet: "Tables by WP Type," rows 253 to 258.

Seismic events causing waste package-pallet impacts that can damage a codisposal waste package are shown in Table 2.1.14.19.0A-2. The range of the seismic events is shown in the column labeled "PGV Value" with the associated annual exceedance frequencies in columns 2 and 3.

with Potential to Cause

Table 2.1.14.19.0A-2. Probability of Seismic Vibratory Ground Motion Events ~~Causing~~ Damage to Codisposal Waste Packages

PGV Value (m/s)	λ_1 (Events/year)	λ_2 (Events/year)	t_1 (years)	t_2 (years)	Probability
< 0.364	1.27×10^{-4}	NA	NA	NA	NA
0.364 to 0.4	9.30×10^{-5}	1.27×10^{-4}	10,000	0	2.87×10^{-1}
0.4 to 1.05	9.96×10^{-6}	9.30×10^{-5}	10,000	0	5.64×10^{-1}
1.05 to 2.44	4.52×10^{-7}	9.96×10^{-6}	10,000	0	9.07×10^{-2}
2.44 to 4.07	1.0×10^{-8}	4.52×10^{-7}	10,000	0	4.41×10^{-3}

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Source: DTN: MO0705CRITPROB.000 [DIRS ~~184958~~], file: *Fault Displacement Abstraction for Criticality Updated DTN 10-25-07.xls*, worksheet: "Tables by WP Type," rows 250 to

. Integrating over the distribution for seismic hazard (Tables 2.1.14.19.0A-1 and 2.1.14.19.0A-2) results in a probability of damage for a TAD waste package given by Table 2.1.14.19.0A-3 as 1.57×10^{-4} for the 90% RST level, and zero for a damage threshold at either the 100% and 105% RST levels.

Probability of waste package OCB damage from effects of the ground motion—If a seismic vibratory ground motion event occurs, the estimated probability of damage to a TAD canister-bearing waste package from impacts is given as 0.118 (SNL 2007 [DIRS 176828], Section 6.5.1.2) at the 90% RST level at the 4.07 m/s PGV range, ~~resulting in a probability of damage for a TAD canister-bearing waste package given by 4.41 × 10^−3^ × (0.0 + 0.118) × 0.5 = 2.6 × 10^−4^. The probability of damage at the 100% RST level is zero. Since the probability of damage (i.e., 0.118) is a point estimate evaluated at discrete PGV levels, the probability over the frequency range is assigned the average value.~~ The 90% RST level data is used for conservatism for the initiating event probability values.

Similarly, the estimated probability of damage to a codisposal waste package from impacts is given in Table 2.1.14.19.0A-3, assuming a damage threshold at the 90% RST level, resulting in a probability of damage to a codisposal waste package of 0.196 and 0.004 at the 90% and 100% RST levels, respectively. The estimated probability of damage from impacts for a codisposal waste package is zero, assuming a damage threshold at the 105% RST level. The 90% RST level data is used for conservatism for the initiating event probability values.

~~given in Table 2.1.14.19.0A-3 at the 90% RST level for PGV values between 0.4 and 4.07 m/s inclusively and at 100% RST level for PGV values between 2.44 and 4.07 m/s inclusively.~~

~~Table 2.1.14.19.0A-3. Probability of Damage for Intact Codisposal Waste Package~~

~~PGV Level (m/s)~~	~~Residual Stress Threshold as Percentage of Yield Strength~~		
	~~90%~~	~~100%~~	~~105%~~
~~0.364~~	~~0~~	~~0~~	~~0~~
~~0.4~~	~~0.029~~	~~0~~	~~0~~
~~1.05~~	~~0.559~~	~~0~~	~~0~~
~~2.44~~	~~0.941~~	~~0.147~~	~~0~~
~~4.07~~	~~1~~	~~0.412~~	~~0~~

New Table Here (see image in ERD body)

~~Source: DTN: MO0703PASDSTST.001 [DIRS 183148], file: *CDSP Kinematic Damage Abstraction 23 mm Intact.xls*, worksheet: "Probability of Damage - New."~~

~~Combining the information from Tables 2.1.14.19.0A-2 and 2.1.14.19.0A-3 results in a probability of damage to a codisposal waste package at the 90% and 100% RST levels, respectively, of (0.29 × (0.0 + 0.03) + 0.56 × (0.03 + 0.56) + 0.091 × (0.56 + 0.94) + 0.0044 ×~~

~~(0.94 + 1.0)) × 0.5 = 0.24 and (0.091 × (0.0 + 0.147) + 0.0044 × (0.147 + 0.412)) × 0.5 = 7.9 × 10^{-3}. The estimated probability of damage from impacts for a codisposal waste package is zero for the 105% RST level. The 90% RST level data is used for conservatism for the initiating event probability values.~~

Probability of improper absorber material in a CSNF or DOE SNF canister—These types of events (e.g., incorrect material installed during fabrication, absorber content ~~of plates~~ outside specified range) can only occur during fabrication and/or loading of a canister due to process or procedural errors. Errors in fabrication and operational processes are primarily due to human factors that are common to the various processes. Surrogate fabrication and operational processes with associated human factor errors have been evaluated in *Analysis of Mechanisms for Early Waste Package/Drip Shield Failure* (SNL 2007 [DIRS 178765]), and results are used for such initiating events such as improper performance of the neutron absorber ~~plates~~ represented as a material selection error in the waste package component fabrication processes (SNL 2007 [DIRS 178765], Section 6.3.2). The mean value of the probability distribution for a fabrication failure is 1.25 × 10^{-7} per canister (DTN: MO0705EARLYEND.000 [DIRS 180946], file: *Table 1.doc*, Table 1).

Probability of Loading Curve Violation—An analysis of commercial SNF misload probabilities was documented in *Commercial Spent Nuclear Fuels Waste Package Misload Analysis* (BSC 2003 [DIRS 166316]). Results from this analysis establish that the probability of a loading curve violation in a 21-PWR waste package is 1.18 × 10^{-5} (BSC 2003 [DIRS 166316], Table 41). The TAD canister specifications require the canisters for PWR SNF to contain 21 assemblies similar to the 21-PWR waste package (SNL 2007 [DIRS 179394], Section 4.1.1.2). The cited analysis is used as a surrogate for misloading waste forms in a TAD canister since the misloading of an assembly into a TAD canister requires the same improper selection of an assembly with characteristics (burnup and enrichment) in the unacceptable range of the loading curve. Thus, the probability of a loading curve violation for TAD canisters is expected to be similar in magnitude to the 21-PWR waste package value. However, neighboring assemblies that have low reactivity values may provide partial compensation for the excess reactivity from the incorrectly loaded assembly. Given that a misloading curve violation occurs, the likelihood of the misloaded configuration having potential for criticality has been shown to be 0.014 from results of a probabilistic calculation of that potential (SNL 2008 [DIRS 182788], Section 7). The probability of a potentially critical configuration resulting from an assembly misload of a 21-PWR TAD canister is $0.014 \times 1.18 \times 10^{-5} = 1.65 \times 10^{-7}$ per TAD canister.

The probability of misloading assemblies in the 44-BWR TAD canister is insignificant since the entire expected BWR inventory for the repository is in the acceptable region of the loading curve map (SNL 2008 [DIRS 182788], Section 6.1.1.1.3). Misloading of waste forms in DOE SNF canisters is considered very improbable because the shape and size of the defense HLW glass canisters and the various DOE SNF canisters differ significantly and can be readily distinguished by visual inspection. Thus, the waste form misload probability for DOE SNF waste packages is considered to be sufficiently low such that, if quantified, would not significantly increase the overall probability of criticality in the repository.

Probability of drip shield failure—Significant rockfall onto and around the drip shields resulting in drip shield rupture is unlikely to occur (probability of 1.8 × 10^{-4} for PWR SNF repository wide for 10,000 years in the lithophysal unit) (DTN: MO07~~12~~810PBANLNWP~~.000~~.001 [DIRS ~~184664~~185947]). The likelihood of such damage in the lithophysal and nonlithophysal zones is discussed in *Seismic Consequence Abstraction* (SNL 2007 [DIRS 176828], Sections 6.8.2.2 and 6.10.2). The probability of the waste package OCB failing during the 10,000-year period following repository closure, given conditions for localized corrosion (included FEP 2.1.03.03.0A (Localized Corrosion of Waste Packages)), has been evaluated for both geologic units in DTNs: MO07~~12~~810PANLNNWP~~.000~~.001 [DIRS ~~184480~~185842] and MO07~~12~~810PBANLNWP~~.000~~.001 [DIRS ~~184664~~185947]. The combined probabilities associated with the events that would be necessary for criticality to be possible are presented in Table 2.1.14.19.0A-4. These probabilities are based on the TSPA localized corrosion model combined with seismic information for rockfall and drip shield fragility curves in conjunction with the probability of absorber misload and assembly misload for the 21-PWR TAD waste package.

Table 2.1.14.19.0A-4. Probability of Potential Criticality from Waste Package OCB Failure from Localized Corrosion due to Drip Shield Rupture from Rockfall Loading

Criticality Event Sequence	Probability
PWR TAD Canister Loading Curve Violation	~~5.9×10^{-10}~~ 7.2×10^{-9}
PWR TAD Canister Absorber Misload	~~4.4×10^{-10}~~ 5.5×10^{-9}
BWR TAD Canister Absorber Misload	~~2.8×10^{-10}~~ 3.5×10^{-9}
DOE SNF Canister Absorber Misload	~~2.8×10^{-10}~~ 4.1×10^{-10}

Source: SNL 2008 [DIRS 173869], Table 6.4-7.

Criticality following a seismic breach—Evaluating the event sequences resulting from breaches that are not fault induced or localized corrosion induced for commercial SNF and DOE SNF using the number of 21-PWR TAD canisters as 4,568, the number of 44-BWR TAD canisters as 2,915, and DOE SNF canisters that require neutron absorber plates (DOE1, DOE2, and DOE7 groups) as 1,223 (SNL 2008 [DIRS 173869], Section 6.4.2) and setting the number of drip shields equal to the number of waste packages gives:

21-PWR TAD canister loading curve violation:

~~2.6~~ 1.57 $\times 10^{-4} \times \{1-P_B\,(0; (1.65 \times 10^{-7}), 4568)\} =$ ~~2.0~~ 1.2 $\times 10^{-7}$

21-PWR TAD canister absorber misload:

~~2.6~~ 1.57 $\times 10^{-4} \times \{1-P_B\,(0; (1.25 \times 10^{-7}), 4568)\} =$ ~~1.5×10^{-7}~~ 9.0×10^{-8}

44-BWR TAD canister absorber misload:

~~2.6~~ 1.57 $\times 10^{-4} \times \{1-P_B\,(0; (1.25 \times 10^{-7}), 2915)\} =$ ~~9.5~~ 5.7 $\times 10^{-8}$

DOE SNF canister absorber plate misload (DOE1, DOE2, and DOE7):

~~0.24~~ 0.196 $\{1-P_B\,(0; (1.25 \times 10^{-7}), 1223)\} =$ ~~3.7~~ 3.0 $\times 10^{-5}$

~~Thus, a conservative estimate for the probability of achieving a configuration with criticality potential in the repository resulting from seismic vibratory induced impact damage, assuming a damage threshold at the 90% RST level, with subsequent SCC breaching of the waste package~~

~~OCB for commercial SNF and DOE SNF, based on summing this set of events, including the DOE1, DOE2, and DOE7 contributions, is 3.7×10^{-5} for 10,000 years. In actuality, the number of DOE waste packages that have sufficient criticality potential to require absorber plate cr~~ ~~th~~ ~~be~~ ~~le~~ ~~ev~~ ~~a~~ ~~po~~ ~~estimating the probability of impact damage to codisposal waste packages reduced the estimated probability of vibratory impact damage to the codisposal waste packages by approximately 20% (DTN: MO0705CRITPROB.000 [DIRS 184958], file: *CSNF TAD & CDSP WP Impact damage.xls*).~~

Evaluating the event sequences for DOE SNF accounting for the probability of neutron absorber shot misload for the DOE1 (MOX), DOE5 (U/Th Oxide), and DOE8 (U-Zr/U-Mo alloy) waste forms, the estimated canister misload probability for these waste forms is given by:

DOE SNF canister absorber shot misload (214 DOE1, DOE5, and DOE8 canisters, (SNL 2008 [DIRS 173869] Section 6.4.2.1):

$0.196 \times \{1-P_B (0; (1.25 \times 10^{-7}), 214)\} = 5.2 \times 10^{-6}$

Thus, a conservative estimate for the probability of achieving a configuration with criticality potential in the repository resulting from seismic vibratory induced impact damage, assuming a damage threshold at the 90% RST level, with subsequent SCC breaching of the waste package OCB for commercial SNF and DOE SNF, based on summing this set of events, combining the DOE1 (absorber plate and shot error), DOE2, DOE5, DOE7, and DOE8 contributions is 3.5×10^{-5} for 10,000 years (SNL 2008 [DIRS 173869], Section 6.4.2.1). These results have been developed on a very conservative basis (e.g., use of damage probabilities at the 90% RST level). The probabilities evaluated from the complete event sequences are expected to be significantly lower than from using a truncated sequence of events to estimate the probability of achieving a configuration with potential for criticality.

Seismic Faulting

Results from analyses of waste package damage due to fault displacement during a seismic event are documented in *Seismic Consequence Abstraction* (SNL 2007 [DIRS 176828], Section 6.11.7) and FEP. The information for the criticality analysis is consistent with the methodology for the damage abstraction for fault displacement in the TSPA, but represents a finer level of detail. The finer level of detail is based on the damage abstraction for the TSPA being based on two waste package groups: the TAD canister group and the codisposal group. While this grouping is consistent with the representation of waste package groups in the TSPA, criticality studies require a more detailed analysis of waste package failures by individual waste package type. The calculations for the criticality analysis are given in *Fault Displacement Abstraction for Criticality.xls* derived from DTN: MO0705FAULTABS.000 [DIRS 183150]) updated to the waste package inventory from *Screening Analysis of Criticality Features, Events, and Processes for License Application* (SNL 2008 [DIRS 173869], Table 4.1-2).

Events considered in the seismic faulting scenario requiring probability values for the calculation are listed as follows:

1. Probability of a seismic faulting event over an exceedance range where sufficient displacement can shear waste packages
2. Number of failed waste packages for a seismic faulting event
3. Probability of improper absorber material in a TAD or DOE SNF canister
4. Probability of a loading curve violation for a 21-PWR TAD canister.

Fractional lengths of the various waste package types in the inventory, which are used to determine the expected number of waste package failures from faulting, are listed in Table 2.1.14.19.0A-5. Table 2.1.14.19.0A-6 provides the expected number of waste packages by type that are emplaced on each fault. Tables 2.1.14.19.0A-7 and 2.1.14.19.0A-8 show the result of combining the exceedance frequencies that cause failure and the number of packages emplaced on faults in Table 2.1.14.19.0A-6 to determine the cumulative number of waste packages expected to fail by type as a function of annual exceedance frequency.

Table 2.1.14.19.0A-5. Fractional Length per Waste Package Variant

Waste Package Type	**Nominal Quantity**	**Total Length of Waste Package Type (mm)**	**Fraction of Waste Packages (% of Total Length)**
CSNF TAD Canister	7,483	4.378×10^7	74.7
CDSP Short	1,600	5.196×10^6	10.1
CDSP Long	1,474	7.818×10^6	13.3
CDSP MCO	210	1.109×10^6	1.9

Sources: DTN: MO0705CRITPROB.000 [DIRS ~~184958~~], file: *Fault Displacement Abstraction for Criticality Updated DTN 10-25-07.xls*, worksheet: "Tables by WP Type."

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Table 2.1.14.19.0A-6. Expected Number of Waste Packages by Type Emplaced on Faults

Fault	**Commercial SNF TAD Canister**	**Codisposal Short**	**Codisposal Long**	**Codisposal MCO**
3 - Drill Hole Wash, Pagany Wash, & Sever Wash	19.4	2.6	3.5	1.5
4 – West Ghost Dance	8.2	1.1	1.5	0.2
5 – Sundance	4.5	0.6	0.8	0.1
Sites 7a/8a	127.7	17.3	22.8	3.2
Totals	159.8	21.6	28.5	4.0

Source: DTN: MO0705CRITPROB.000 [DIRS ~~184958~~], file: *Fault Displacement Abstraction for Criticality Updated DTN 10-25-07.xls*, worksheet: "Tables by WP Type", rows 177 to 187.

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Table 2.1.14.19.0A-7. Cumulative Number of Failed Commercial SNF Waste Packages Expected versus Annual Exceedance Frequency

Exceedance Frequency Range (1/yr)	**Commercial SNF TAD Canister**
> 8.2×10^{-8}	0
7.0×10^{-8} to 8.2×10^{-8}	19.4
2.7×10^{-8} to 7.0×10^{-8}	27.6
1.0×10^{-8} to 2.7×10^{-8}	32.1

Source: DTN: MO0705CRITPROB.000 [DIRS ~~184958~~], file: *Fault Displacement Abstraction for Criticality Updated DTN 10-25-07.xls*, worksheet: "Tables by WP Type," rows 189 to 197.

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Table 2.1.14.19.0A-8. Cumulative Number of Failed Codisposal Waste Packages Expected versus Annual Exceedance Frequency

Exceedance Frequency Range (1/yr)	Expected Number of Failures Codisposal Short	Expected Number of Failures Codisposal Long	Exceedance Frequency Range (1/yr)	Expected Number of Failures Codisposal MCO
$> 1.2 \times 10^{-7}$	0	0	$> 6.3 \times 10^{-8}$	0
1.1×10^{-7} to 1.2×10^{-7}	2.6	3.5	5.4×10^{-8} to 6.3×10^{-8}	0.5
4.1×10^{-8} to 1.1×10^{-7}	3.7	4.9	2.1×10^{-8} to 5.4×10^{-8}	0.7
1.3×10^{-8} to 4.1×10^{-8}	4.3	5.7	1.0×10^{-8} to 2.1×10^{-8}	0.8
1.0×10^{-8} to 1.3×10^{-8}	21.6	28.5		

Source: DTN: MO0705CRITPROB.000 [DIRS ~~184958~~], file: *Fault Displacement Abstraction for Criticality Updated DTN 10-25-07.xls*, worksheet: "Tables by WP Type," rows 189 to 198.

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For seismic events with an annual exceedance frequency greater than 1.2×10^{-7} per year (i.e., less severe earthquakes), no waste package damage is expected to occur due to faulting as shown in Tables 2.1.14.19.0A-7 and 2.1.14.19.0A-8. For seismic events with an annual exceedance frequency less than 1.2×10^{-7} per year (i.e., more severe earthquakes), waste package failure from seismically induced faulting is initiated. The number of failed waste packages increases with increasing seismic energy (decreasing annual exceedance frequency) to a maximum number that depends on waste package variant as shown in Tables 2.1.14.19.0A-7 and 2.1.14.19.0A-8. The annual exceedance frequency range for the commercial SNF TAD canister and codisposal waste packages is subdivided into three or four ranges for this analysis, depending on the waste package variant as shown in the column labeled "Exceedance Frequency Range" in Tables 2.1.14.19.0A-7 and 2.1.14.19.0A-8 for each waste package variant. The probabilities of these basic events are determined with Equation 2.1.14.19.0A-1 and the information provided in Table 2.1.14.19.0A-9.

Table 2.1.14.19.0A-9. Probabilities of Seismic Faulting Events with Waste Package Failure Capability

Commercial SNF TAD Waste Package Variant					
PGV Value (m/s)	λ_1 (events/year)	λ_2 (events/year)	t_1 (years)	t_2 (years)	**Probability**
4.07 to 3.77	1.0×10^{-8}	2.7×10^{-8}	10,000	0	1.7×10^{-4}
3.77 to 3.41	2.7×10^{-8}	7.0×10^{-8}	10,000	0	4.3×10^{-4}
3.41 to 3.34	7.0×10^{-8}	8.2×10^{-8}	10,000	0	1.2×10^{-4}
Codisposal Waste Package Variant					
4.07 to 4.00	1.0×10^{-8}	1.3×10^{-8}	10,000	0	3.0×10^{-5}
4.00 to 3.62	1.3×10^{-8}	4.1×10^{-8}	10,000	0	2.8×10^{-4}
3.62 to 3.21	4.1×10^{-8}	1.1×10^{-7}	10,000	0	6.9×10^{-4}
3.21 to 3.18	1.1×10^{-7}	1.2×10^{-7}	10,000	0	1.0×10^{-4}

Source: DTN: MO0705CRITPROB.000 [DIRS ~~184958~~], file: *Fault Displacement Abstraction for Criticality Updated DTN 10-25-07.xls*, worksheet: "Tables by WP Type," rows 203 to 209.

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The mean probability of a seismic faulting event is a point value derived from the probability of a seismic event with faulting as given in Table 2.1.14.19.0A-9 multiplied by the incremental number of waste packages with criticality potential being impacted within each frequency range given in Tables 2.1.14.19.0A-7 and 2.1.14.19.0A-8.

The probabilities of the remaining events in this scenario were discussed above and resulted in the following: The probability of installing improper absorber plate material in a TAD canister is 1.25×10^{-7} per canister, and the probability of a potentially critical configuration resulting from an assembly misload of a 21-PWR TAD canister is 1.65×10^{-7} per TAD canister.

Evaluating the event sequences for commercial SNF and DOE SNF using the fractions of 21-PWR TAD canisters (4,568/7,483), 44-BWR TAD canisters (2,915/7,483), and DOE SNF canisters that require neutron absorber plates (DOE1, DOE2, and DOE7 groups) (1,223/3,074) (SNL 2008 [DIRS 173869], Section 6.4.3) gives:

PWR TAD canister loading curve violation:

$1.2 \times 10^{-4} \times (1-P_B$ (0; 1.65×10^{-7}, ($19.4 \times 4568/7483$)) + $4.3 \times 10^{-4} \times (1-P_B$ (0; 1.65×10^{-7}, (27.6 ~~−19.4~~) × 4568/7483)) +$1.7 \times 10^{-4} \times (1-P_B$ (0; 1.65×10^{-7}, (32.1 ~~− 27.6~~) × 4568/7483))
= ~~6.3 × 10⁻¹⁰~~ 1.9 x 10^{-9}

PWR TAD canister absorber misload:

$1.2 \times 10^{-4} \times (1-P_B$ (0; 1.25×10^{-7}, ($19.4 \times 4568/7483$)) + $4.3 \times 10^{-4} \times (1-P_B$ (0; 1.25×10^{-7}, (27.6 ~~−19.4~~) × 4568/7483)) +$1.7 \times 10^{-4} \times (1-P_B$ (0; 1.25×10^{-7}, (32.1 ~~− 27.6~~) × 4568/7483))
= ~~4.8 × 10⁻¹⁰~~ 1.4 x 10^{-9}

44-BWR TAD canister absorber misload:

$1.2 \times 10^{-4} \times (1\ P_B$ (0; 1.25×10^{-7}, ($19.4 \times 2915/7483$)) + $4.3 \times 10^{-4} \times (1-P_B$ (0; 1.25×10^{-7}, (27.6 ~~− 19.4~~) × 2915/7483)) +$1.7 \times 10^{-4} \times (1-P_B$ (0; 1.25×10^{-7}, (32.1 ~~− 27.6~~) × 2915/7483))
= ~~2.9 × 10⁻¹⁰~~ 9.0 x 10^{-10}

plate

DOE SNF canister absorber misload (DOE1, DOE2, and DOE7):

$1.0 \times 10^{-4} \times (1-P_B$ (0; 1.25×10^{-7}, (2.6+3.5) × 1223/3074)) + $6.9 \times 10^{-4} \times (1-P_B$ (0; 1.25 × 10^{-7}, (3.7~~−2.6~~ + 4.9~~−3.5~~) × 1223/3074)) + $2.8 \times 10^{-4} \times (1-P_B$ (0; 1.25×10^{-7}, (4.3~~−3.7~~ + 5.7~~−4.9~~) × 1223/3074)) + $3.0 \times 10^{-5} \times (1-P_B$ (0; 1.25×10^{-7}, (21.6~~−4.3~~ + 28.5~~−5.7~~) × 1223/3074)) = ~~8.1 × 10⁻¹¹~~ 5.4 x 10^{-10}

~~Thus, a conservative estimate for the probability of achieving a configuration with criticality potential in the repository resulting from a seismic faulting initiating event for commercial SNF and DOE SNF is 1.5 × 10⁻⁹ for 10,000 years.~~

Summary—The events in the short sequences are considered as the principal contributors to the probability of occurrence of configurations having criticality potential following a seismic

Evaluating the event sequences for DOE SNF with the probability of neutron absorber shot misload for the DOE1 (MOX), DOE5 (U/Th Oxide), and DOE8 (U-Zr/U-Mo alloy) waste forms is given by:
DOE SNF canister absorber shot misload (214 DOE1, DOE5, and DOE8 canisters, (SNL 2008 [DIRS 173869], Section 6.4.3):
1.0 x 10^{-4} (1-P_B (0; 1.25 x 10^{-7}, (2.6+3.5) 214/3074)) + 6.9 x 10^{-4} (1-P_B (0; 1.25 x 10^{-7}, (3.7 + 4.9) 214/3074)) + 2.8 x 10^{-4} (1-P_B (0; 1.25 x 10^{-7}, (4.3 + 5.7) 214/3074)) + 3.0 x 10^{-5} (1-P_B (0; 1.25 x 10^{-7}, (21.6 + 28.5) 214/3074)) = 9.4 x 10^{-11}.
Thus, a conservative estimate for the probability of achieving a configuration with criticality potential in the repository resulting from a seismic faulting initiating event for commercial SNF and DOE SNF, combining the DOE1 (absorber plate and shot error), DOE2, DOE5, DOE7, and DOE8 contributions is 4.8 x 10^{-9} for 10,000 years.

probability of criticality of ~~3.7~~ 3.55 × 10^{-5} over 10,000 years (SNL 2008 [DIRS 173869] Table 7.1-1). This is less than 1 chance in 10,000 (1×10^{-4}) of occurrence within 10,000 years of disposal. Accordingly, FEP 2.1.14.19.0A (In-Package Criticality Resulting from a Seismic Event (Degraded Configurations) is excluded from the performance assessments conducted to demonstrate compliance with proposed 10 CFR 63.311 and 63.321 (70 FR 53313 [DIRS 178394]), and with 10 CFR 63.331 [DIRS 180319], on the basis of low probability.

In addition, as documented in *Screening Analysis of Criticality Features, Events, and Processes for License Application* (SNL 2008 [DIRS 173869], Section 7.1), the probability of criticality for all locations is less than 1 chance in 10,000 of occurrence within 10,000 years after disposal. The results documented in this analysis are applicable for all waste forms and waste package variants.

INPUTS:

Table 2.1.14.19.0A-10. Direct Inputs

Input	Source	Description
BSC 2003. *Commercial Spent Nuclear Fuel Waste Package Misload Analysis*. [DIRS 166316]	Table 41	Error probabilities for commercial SNF waste package loading violation
BSC 2004. *Intact and Degraded Mode Criticality Calculations for the Codisposal of ATR Spent Nuclear Fuel in a Waste Package*. [DIRS 171926]	Section 6	Criticality potential of DOE SNF waste forms
BSC 2004. *Intact and Degraded Mode Criticality Calculations for the Codisposal of TMI-2 Spent Nuclear Fuel in a Waste Package*. [DIRS 168935]	Section 6	Criticality potential of DOE SNF waste forms
DTN: MO0703PASDSTAT.001. Statistical Analyses for Seismic Damage Abstractions. [DIRS 183148]	file: *Kinematic Damage Abstraction 23-mm Intact.xls*, worksheet: "Probability of Damage"	For seismic events causing waste package-pallet impacts that can damage a commercial SNF waste package at the 90% residual stress level, at a PGV value of 4.07 (exceedance frequency of 1×10^{-8} per year), the probability of impact damage is 0.118
	file: *CDSP Kinematic Damage Abstraction 23-mm Intact.xls*, worksheet: "Probability of Damage – New"	Probability of seismic vibratory ground motion events causing damage to codisposal waste packages
DTN: MO0705CRITPROB.000. Probability of Criticality. [DIRS ~~184958~~] 186328	file: *Fault Displacement Abstraction for Criticality Updated DTN 10-25-07.xls*, worksheet: "Tables by WP Type," rows: 250 to 256	Probability of seismic vibratory ground motion events causing damage to codisposal waste packages
	file: *Fault Displacement Abstraction for Criticality Updated DTN 10-25-07.xls*, worksheet: "Tables by WP Type," rows: 203 to 209	Commercial SNF TAD waste package variant

Table 2.1.14.19.0A-10. Direct Inputs (Continued)

Input	Source	Description
DTN: MO0705CRITPROB.000. Probability of Criticality. [DIRS ~~184958~~ 186328] (continued)	file: *Fault Displacement Abstraction for Criticality Updated DTN 10-25-07.xls*, worksheet: "Tables by WP Type," rows: 189 to 198	Cumulative number of failed codisposal waste packages expected versus annual exceedance frequency
	file: *Fault Displacement Abstraction for Criticality Updated DTN 10-25-07.xls*, worksheet: "Tables by WP Type," rows: 189 to 197	Cumulative number of failed CSNF waste packages expected versus anual exceedance frequency
	file: *CSNF TAD & CDSP WP Impact damage.xls*	Using a maximum of 35 intervals in the hazard curve for estimating the probability of impact damage to codisposal waste packages reduced the estimated probability of vibratory impact damage to the codisposal waste packages by approximately 20%
	file: *Fault Displacement Abstraction for Criticality Updated DTN 10-25-07.xls*, worksheet: "Tables by WP Type," rows: 253 to 258	TAD waste package variants
	file: *Fault Displacement Abstraction for Criticality Updated DTN 10-25-07.xls*, worksheet: "Tables by WP Type"	Fractional length per waste package variant
	file: *Fault Displacement Abstraction for Criticality Updated DTN 10-25-07.xls*, worksheet: "Tables by WP Type," rows: 177 to 187	Expected number of waste packages by type emplaced on faults
DTN: MO0705EARLYEND.000. Waste Package/Drip Shield Early Failure End State Probabilities. [DIRS 180946]	file: *Table 1.doc*, Table 1	Error probabilities for fabrication and operational processes representing waste package and drip shield early failure mechanisms
DTN: MO0705FAULTABS.000. Assessment of Waste Package Failure Due to Fault Displacement for Criticality. [DIRS 183150]	file: *Fault Displacement Abstraction for Criticality.xls*, worksheet: "Tables by WP Type"	Expected number of waste packages by type emplaced on faults
	file: *Fault Displacement Abstraction for Criticality.xls*, worksheet: "Tables by WP Type"	Cumulative number of failed commercial SNF waste packages expected versus annual exceedance frequency
	file: *Fault Displacement Abstraction for Criticality.xls*, worksheet: "Tables by WP Type"	For seismic events with an annual exceedance frequency greater than 1.2×10^{-7} per year (i.e., less-severe earthquakes), no waste package damage is expected to occur due to faulting

Table 2.1.14.19.0A-10. Direct Inputs (Continued)

Input	Source	Description
SNL 2008. CSNF *Loading Curve Sensitivity Analysis*. [DIRS 182788] (continued)	Section 6.1.1.1.3	Probability of a critical configuration resulting from a BWR SNF waste package loading violation
	Section 6.2.5	The PWR SNF waste form in various degraded configurations such as saturated porous schoepite does not result in a more reactive configuration than the design basis configuration
SNL 2008. *Screening Analysis of Criticality Features, Events, and Processes for License Application*. [DIRS 173869]	Section 6.3.2	Cladding is considered breached within a damaged or failed waste package and the interior of the fuel rods are assumed to be exposed to the repository environment allowing the fissile material to convert to the mineral schoepite (UO$_3$:2H$_2$O)
	Section 6.3.2	Waste package inventory by type
	Section 7.1	Probability of criticality for all locations is less than 1 chance in 10,000 of occurrence within 10,000 years after disposal
	Table 6.4-7	Probability of potential criticality from waste package OCB failure from localized corrosion due to drip shield rupture from rockfall loading

Table 2.1.14.19.0A-11. Indirect Inputs

Citation	Title	DIRS
10 CFR 63	Energy: Disposal of High-Level Radioactive Wastes in a Geologic Repository at Yucca Mountain, Nevada	180319
70 FR 53313	Implementation of a Dose Standard After 10,000 Years	178394
BSC 2003	*Commercial Spent Nuclear Fuel Waste Package Misload Analysis*	166316
BSC 2004	*Configuration Generator Model*	172494
DTN: MO~~0712~~810PANLNNWP~~.000~~.001	Probabilistic Analysis of Non-Navy Waste Packages	~~184480~~ 185842
DTN: MO~~0712~~810PBANLNWP~~.000~~.001	Probabilistic Analysis of Navy Waste Packages	~~184664~~ 185947
SNL 2007	*Seismic Consequence Abstraction*	176828
SNL 2007	*Analysis of Mechanisms for Early Waste Package/Drip Shield Failure*	178765
SNL 2007	*Geochemistry Model Validation Report: Material Degradation and Release Model*	181165
SNL 2007	*Total System Performance Assessment Data Input Package for Requirements Analysis for TAD Canister and Related Waste Package Overpack Physical Attributes Basis for Performance Assessment*	179394
SNL 2008	*Screening Analysis of Criticality Features, Events, and Processes for License Application*	173869
YMP 2003	*Disposal Criticality Analysis Methodology Topical Report*	165505

180392 MO0701PAKDSUNP.000. Colloidal KDS for U, NP, RA and SN. Submittal date: 04/17/2007.

180508 MO0701PASHIELD.000. Waste Package/Drip Shield Early Failure Probabilities. Submittal date: 04/24/2007.

180391 MO0701PASORPTN.000. Colloidal Sorption Coefficients for PU, AM, TH, CS, and PA. Submittal date: 04/17/2007.

179925 MO0702PASTREAM.001. Waste Stream Composition and Thermal Decay Histories for LA. Submittal date: 02/15/2007.

180514 MO0702PASTRESS.002. Output DTN of Model Report, "Stress Corrosion Cracking of Waste Package Outer Barrier and Drip Shield Materials," ANL-EBS-MD-000005. Submittal date: 04/24/2007.

181990 MO0703PAEVSIIC.000. Evaluation of Stage II Condensation. Submittal date: 07/16/2007.

182029 MO0703PAGENCOR.001. Output from General Corrosion and Localized Corrosion of Waste Package Outer Barrier 2007 Second Version. Submittal date: 07/18/2007.

183148 MO0703PASDSTAT.001. Statistical Analyses for Seismic Damage Abstractions. Submittal date: 09/21/2007.

185278 MO0703PASEISDA.002. Seismic Damage Abstractions for TSPA Compliance Case. Submittal date: 03/17/2008.

180442 MO0704PAPTTFBR.002. Particle Tracking Transfer Functions. Submittal date: 04/12/2007.

183681 MO0705CREEPSCC.000. Supplementary Output DTN from SCC AMR. Submittal date: 05/14/2007.

186328 ~~184958~~ MO0705CRITPROB.000. Probability of Criticality. Submittal date: 08/20/2009 ~~02/05/2008~~.

180946 MO0705EARLYEND.000. Waste Package/Drip Shield Early Failure End State Probabilities. Submittal date: 05/16/2007.

183150 MO0705FAULTABS.000. Assessment of Waste Package Failure Due to Fault Displacement for Criticality. Submittal date: 09/21/2007.

181798 MO0705GEOMODEL.000. Input Files and Model Output Runs: Geochemistry Model Validation Report: Material Degradation and Release Model. Submittal date: 05/23/2007.

185041 MO0705OXYBALAN.000. Oxygen Balance Analysis for Physical and Chemical Environment. Submittal date: 05/23/2007.

180869 MO0705SCCIGM06.000. Final Report for FY06: Stress Corrosion Crack Initiation & Growth Measurements in Environments Relevant to High Level Nuclear Waste Packages. Submittal date: 05/14/2007.

183008 MO0705TSPASEEP.000. TSPA-LA Addendum, Seepage Results from the TSPA-LA Model. Submittal date: 01/15/2008.

181887 MO0706METMND06.000. Meteorological Monitoring Data for 2006. Submittal date: 06/19/2007.

182472 MO0707TH2D3DDC.000. 2-D and 3-D Thermal-Hydrologic Analysis. Submittal date: 08/15/2007.

182994 MO0709TSPALOCO.000. TSPA Localized Corrosion Analysis. Submittal date: 09/13/2007.

182976 MO0709TSPAREGS.000. TSPA-LA Model (GW & E) Used for Regulatory Compliance. Submittal date: 09/04/2007.

184172 MO0712DELNPCCA.001. Delineation of Postclosure Controlled Area. Submittal date: 12/03/2007.

185842 ~~184480~~ MO0~~712~~810PANLNNWP.~~000~~001. Probabilistic Analysis of Drip Shield Failure and CSNF and CDSP Package OCB Localized Corrosion. Submittal date: ~~12/17/2007~~ 10/21/2008.

185947 ~~184664~~ MO0~~712~~810PBANLNWP.~~000~~001. Probabilistic Analysis of Navy Waste Packages. Submittal date: ~~12/13/2007~~ 10/21/2008

109059 MO9906GPS98410.000. Yucca Mountain Project (YMP) Borehole Locations. Submittal date: 06/23/1999.

165922 MO9912GSC99492.000. Surveyed USW SD-6 As-Built Location. Submittal date: 12/21/1999.

166458 SN0308F3710195.003. Hydraulic Fracturing Stress Measurements in Test Holes: ESF-GDJACK #1, and ESF-GDJACK #5, Exploratory Studies Facility at Yucca Mountain, Nevada. Submittal date: 08/29/2003.

168761 SN0310T0505503.004. Initial Radionuclide Inventories for TSPA-LA. Submittal date: 10/27/2003.

174472 SN0506F4104405.003. Analyses of Phase I and Phase II Data from the Stress Corrosion Crack Flow Tests (Data from 1/12/2005 to 5/13/2005). Submittal date: 06/20/2005.

179063 SN0609T0502206.024. Monsoon Net Infiltration Results. Submittal date: 09/18/2006.

178753 SN0609T0502206.028. Present-Day Net Infiltration Results. Submittal date: 09/22/2006.

178862 SN0609T0502206.029. Glacial Transition Net Infiltration Results. Submittal date: 09/28/2006.

178850 SN0612T0502404.014. Thermodynamic Database Input File for EQ3/6 - DATA0.YMP.R5. Submittal date: 12/15/2006.

178956 SN0612T0510106.004. Saturated Zone (SZ) Site-Scale Flow Model Pest and FEHM Files Using HFM2006. Submittal date: 01/17/2007.

180523 SN0701PAEBSPCE.001. PCE TDIP Potential Seepage Water Chemistry Lookup Tables. Submittal date: 04/25/2007.

184289 SN0701T0502206.037. Massif Calculation of Net Infiltration at Yucca Mountain, Rev 1. Submittal date: 12/10/2007.

186224 ~~180451~~ SN0702PAIPC1CA.001. In-Package Chemistry Calculations and Abstractions. Submittal date: ~~04/19/2007.~~ 04/10/2009

179575 SN0702T0510106.006. Saturated Zone (SZ) Site-Scale Flow Model with “Water Table Rise” Alternate Conceptual Model - FEHM Files Using HFM2006. Submittal date: 02/19/2007.

181571 SN0703PAEBSPCE.006. Physical and Chemical Environment (PCE) TDIP Water-Rock Interaction Parameter Table and Salt Separation Tables with Supporting Files. Submittal date: 06/27/2007.

183217 SN0703PAEBSRTA.001. Inputs Used in the Engineered Barrier System (EBS) Radionuclide Transport Abstraction. Submittal date: 09/28/2007.

182122 SN0704PADSGCMT.001. Drip Shield General Corrosion Models Based on 2.5-Year Titanium Grade 7 Corrosion Rates. Submittal date: 07/24/2007.

181283 SN0704T0510106.008. Flux, Head and Particle Track Output from the Qualified, Calibrated Saturated Zone (SZ) Site-Scale Flow Model. Submittal date: 05/01/2007.

131356 SNF37100195002.001. Hydraulic Fracturing Stress Measurements in Test Hole: ESF-AOD-HDFR1, Thermal Test Facility, Exploratory Studies Facility at Yucca Mountain. Submittal date: 12/18/1996.

The flow rate through the cracks ($F_{WP\_seepage}$) is estimated by multiplying the impinging drift seepage flux ($F_{WP\_impinging\_drips}$) with a crack seepage scaling factor (f_{crack_seeps}) that is based on the data from the dynamic drip tests on Stainless Steel Type 316 and Titanium Grade 7 test blocks with varying shapes and aperture sizes of cracks, including actual SCC cracks in a large stainless steel plate (DTN: SN0506F4104405.003 [DIRS 174472], files: *Dynamic_Drop_Test_Summary_SCC_4-15-05.doc* and *SCC_PhaseII_Test_Preliminary_Summary_9-21-05.doc*).

$$F_{WP\_seepage} = f_{crack\_seeps} \times F_{WP\_impinging\_drips} \qquad \text{(Eq. C-12)}$$

The crack seepage factor ranges from 0.0 to 0.04, and is characterized as epistemic uncertainty with a uniform distribution between the bounds (0.0 and 0.04).

Using the bounding values for the parameters of this analysis, and the waste package damage from ground motion at the 1.05 m/s PGV level (Section C.2.3.1), the damaged waste package reduces the seepage flux from the SCC-damaged drip shield by more than five orders of magnitude (output DTN: SN0705WFLOWSCC.001, file: *Bounding calc for water flow through SCC cracks.xls*, worksheet: "Impinging drip flow rate," cell: H25). Combined, the SCC-damaged drip shield and waste package can reduce the drift seepage flux on to the drip shield by at least ten orders of magnitude (output DTN: SN0705WFLOWSCC.001, file: *Bounding calc for water flow through SCC cracks.xls*, worksheet: "Impinging drip flow rate," cell: H27). This means that advective flow of seepage through seismic-induced SCC damage in the drip shield and the underlying waste package, is much less than the amount of water that is retained in the corrosion reactions in a breached waste package (SNL 2007 ~~[DIRS 177404]~~, Figure 6.5-8), and is therefore negligible.

[DIRS 177407]

Table C-2. Direct Inputs for Appendix C

Input	Source	Description
DTN: MO0702PASTRESS.002. Output DTN of Model Report, "Stress Corrosion Cracking of Waste Package Outer Barrier and Drip Shield Materials," ANL-EBS-MD-000005. [DIRS 180514]	File: *Model Output DTN.doc*, Table 8-1	Values for yield strength and modulus of elasticity for Titanium Grade 7 and Alloy 22 at room temperature
DTN: MO0703PASDSTAT.001. Statistical Analyses for Seismic Damage Abstractions. [DIRS 183148]	File: *DS Damaged Area with Rubble.xls*, worksheet: "1.05 ms PGV - Case 2 BCs," cells: M57 to M68; worksheet: "1.05 ms PGV - Case 1 BCs," cells: M54 to M65	No damage to the drip shield with the 15-mm plate thickness by rock rubble accumulation and seismic loading in the lithophysal rock zone
	File: *Kinematic Damage Abstraction 23-mm Intact.xls*, worksheet: "WP Total"	No seismic-induced SCC damage to the TAD-bearing waste packages of 23-mm-thick WPOB with intact internals from the 1.05 m/s PGV level ground motions

Table C-2. Direct Inputs (Continued)

Input	Source	Description
SNL 2007. *Mechanical Assessment of Degraded Waste Packages and Drip Shields Subject to Vibratory Ground Motion*. [DIRS 178851]	Table 6-154	The largest rock block (the 99.9th percentile for all blocks ejected for the 1.05 m/s PGV event) considered for this analysis
SNL 2007. ~~*Drift-Scale THC Seepage Model*. [DIRS 177404]~~	Figure 6.5-8	Amount of water that is retained in the corrosion reactions inside a breached waste package
SNL 2007. *Stress Corrosion Cracking of Waste Package Outer Barrier and Drip Shield Materials*. [DIRS 181953]	Sections 6.6.2, 6.8.5.2	SCC cracks in the drip shield and WPOB can be treated as semi-elliptical. The expected maximum length (2c in Equations C-1 and C-2) of a semi-circular crack as it grows to a through-wall crack is at least two times the wall thickness
	Section 6.6.2	Maximum tensile stress across the wall thickness of the dominant stress plane for the yield strength term in Equation C-2

EBS Radionuclide Transport Abstraction [DIRS 177407]

Table C-3. Indirect Inputs for Appendix C

Citation	Title	DIRS
Amer et al. 1985	"Zeta Potential and Surface Area of Calcium Carbonate as Related to Phosphate Sorption"	183684
Bear 1972	*Dynamics of Fluids in Porous Media*	156269
Bruemmer and Thomas 2001	"High-Resolution Analytical Electron Microscopy Characterization of Corrosion and Cracking at Buried Interfaces"	183685
BSC 2001	*Plugging of Stress Corrosion Cracks by Precipitates*	156807
BSC 2004	*Yucca Mountain Site Description*	169734
Domenico and Schwartz 1990	*Physical and Chemical Hydrogeology*	100569
DTN: MO0612WPOUTERB.000	Output from General and Localized Corrosion of Waste Package Outer Barrier Report	182035
DTN: MO0703PASEISDA.002	Seismic Damage Abstractions for TSPA Compliance Case	183156
DTN: MO0705CREEPSCC.000	Supplementary Output DTN from SCC AMR	183681
DTN: SN0506F4104405.003	Analyses of Phase I and Phase II Data from the Stress Corrosion Crack Flow Tests (Data from 1/12/2005 to 5/13/2005)	174472
He et al. 2007	"Temperature Effects on Oxide Film Properties of Grade-7 Titanium"	183687
Holford and Mattingly 1975	"Surface Areas of Calcium Carbonate in Soils"	183686
Hu et al. 2001	*Summary Report on Phase I Feasibility Study of In-Drift Diffusion*	161623
Lide 1991	*CRC Handbook of Chemistry and Physics*	131202
Milnes and Fitzpatrick 1995	"Titanium and Zirconium Minerals"	105911
Siriwardane and Wightman 1983	"Interaction of Hydrogen Chloride and Water with Oxide Surfaces. III. Titanium Dioxide"	183688
SNL 2007	*Seismic Consequence Abstraction*	176828