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Provide a transparent technical basis to demonstrate that the event trees and fault trees used to calculate the early failure probabilities of the waste package and drip shield adequately represent all potentially significant failure sequences.

(a) Provide additional justification for how DOE identifies potential event sequences that could lead to early failure of the waste package or drip shield and the criteria used to exclude event sequences from further analysis in the associated event trees.

(b) Provide additional justification for how DOE considers nominal human actions in the processes identified in SNL (2007a), sections 6.3 and 6.4. State what human actions, if any, were excluded from the event sequences, and provide the criteria used as bases for these exclusions.

Basis: In SAR Section 2.3.6.6.3.2, DOE states that probability for early failure of the waste package was determined by event tree/fault tree analysis using the specific event trees and fault trees found in SNL (2007a). Similar methodology was used to calculate the probability for early failure of the drip shield, as stated in SAR, Section 2.3.6.8.4.3.2. The technical basis for identifying the actions in these analyses does not adequately describe how DOE identifies the selected sets of actions in the event sequences and how DOE excludes other potential actions from the event sequences. In addition, although DOE has identified processes that could lead to early failure (SNL, 2007a, Sections 6.3 and 6.4), DOE must justify why it excluded nominal human actions (i.e., those that do not lead directly to waste package and drip shield defects) that could contribute to reliabilities for the six identified processes.

RAI References

SNL (Sandia National Laboratories). 2007a. Analysis of Mechanisms for Early Waste Package/Drip Shield Failure. ANL-EBS-MD-000076 REV 00. Las Vegas, Nevada: Sandia National Laboratories.

1. RESPONSE

The approach taken for waste package and drip shield early failure evaluation was to systematically review industrially relevant analogues (e.g., boiler and pressure vessels, nuclear fuel rods) to identify the types of defects which can potentially affect waste package or drip shield performance and then evaluate these types of defects for applicability to the repository system (SAR Section 2.3.6.6.2.1). The approach to constructing the event sequences involved identification of key processes and assignment of probabilities of failure of these processes rather than a detailed analysis of each process step in waste package and drip shield handling. Thus, nominal human actions are accounted for through the use of historical failure rates (e.g., improper weld material selection, fuel rod handling, etc.), addressing Part (b) of the RAI.

Literature information on historical occurrence of defects in the following types of containers are evaluated (SAR Section 2.3.6.6.2.1):

- Boilers and pressure vessels
- Nuclear fuel rods
- Underground storage tanks
- Radioactive cesium capsules
- Dry storage casks for SNF.

The fabrication and handling of these container types have similarities to various aspects of drip shield and waste package fabrication, handling, and emplacement. Therefore, the defects identified in these container types are representative of those that could occur in drip shields and waste packages. From these evaluations, eleven types of defects were identified:

- Weld flaws
- Base metal flaws
- Improper weld filler material
- Improper heat treatment (for the waste package, this is separately considered for outer corrosion barrier and outer corrosion barrier closure lid)
- Improper weld-flux material
- Poor weld-joint design
- Surface contamination
- Mislocated welds
- Missing welds
- Handling or installation damage
- Administrative or operational error.

Two other types of defects, out-of-specification base metal and improper stress relief (low-plasticity burnishing) for the closure lid weld, were also determined to be appropriate for further consideration. Thus, there are 13 types of defects considered. These types of defects adequately represent those that could result from the potentially significant failure sequences.

In *Analysis of Mechanisms for Early Waste Package/Drip Shield Failure* (SNL 2007, Section 6.2), waste package and drip shield fabrication and handling processes are summarized and the 13 types of defects identified above are evaluated for applicability to the repository system.

For the waste package, the following six types of defects (the improper heat treatment type of defect is separately considered for outer corrosion barrier and outer corrosion barrier lid) were retained for further analysis:

- Weld flaws
- Improper heat treatment
  - outer corrosion barrier
  - outer corrosion barrier closure lid
- Improper stress-relief of outer corrosion barrier lid (i.e., low plasticity burnishing)
- Waste package mishandling damage
- Improper base metal selection
- Improper weld filler material.

The remaining seven types of defects were dismissed from further analysis on various grounds (SAR Section 2.3.6.6.3.1) as described below:

Improper weld-flux material is not a credible defect source because no weld flux material will be used in waste package fabrication.

Poor weld-joint design is not expected to impact performance due to the significant development and testing effort for weld joint design and waste package prototyping (SAR Sections 1.2.4.2.3 and 1.5.2.6.4).

Surface contamination primarily applies to materials that are sensitive to controlled environment conditions and applications which are unlike the repository waste package components. Fabrication, handling, and inspection requirements for the waste package outer corrosion barrier (SAR Table 1.9-9, design control parameters 03-20 and 03-21) will minimize surface contamination. Therefore, the likelihood of this type of defect being undetected prior to emplacement would be significantly less than the more-dominant defect mechanisms, and on this basis is not further considered.

Mislocated welds are mainly applicable to very small, single-pass welds (e.g., fuel rod end caps). Mislocated welds are not expected for the larger multipass welds on the waste package due to their size, location, significant quality assurance requirements, inspection, and extensive nondestructive evaluation. For large multipass welds, any significant mislocation of the welding electrode would cause the weld arc not to strike. This would be immediately obvious to both the weld operator and the control system for the automated welder.

Data on the occurrence of missing welds in fuel rods indicates that this defect will occur at a rate less than 5×10^{-6} per fuel rod (SNL 2007, Section 6.2.3). Due to their size and multi-pass nature, a missing weld in a waste package would be easier to detect than in a fuel rod. Also, it is expected that the occurrence rate of this defect for a waste package would be significantly less than a more-dominant failure mechanism such as improper heat treatment (i.e., the inclusion of the probability of the occurrence of missing welds would have an insignificant affect on the total waste package early failure probability).

Administrative and operational errors may occur; however, provisions in waste package fabrication, handling, and inspection procedures and equipment design will be made to minimize these errors. Even after taking the planned precautions, these types of errors are still recognized, and the associated rates and consequences are included in the evaluations for the remaining defect modes. For example, the probability of an operator failing to respond to a compelling signal is used in the HT_OPERATOR_ERROR event in the event trees for evaluating improper heat treatment processes as discussed in the response to RAI 3.2.2.1.2.2-003. Therefore, these types of errors are not considered to be separate defect modes.

In addition, waste package emplacement errors have been considered. Because waste package emplacement will be performed under strict controls, and will be monitored remotely by cameras and other electronic sensory equipment (SAR Table 1.3.4-5, postclosure control parameter 05-01), errors in waste package emplacement that could significantly affect repository performance are excluded on the basis of low consequence as discussed in excluded FEP 1.1.03.01.0A, Error in Waste Emplacement (SNL 2008, FEP 1.1.03.01.0A).

The potential for early failure of a drip shield was also evaluated using the same 13 types of defects identified above for the waste packages. The following four defects were retained for further analysis:

- Base metal flaws
- Improper weld filler material
- Improper heat treatment
- Improper drip shield installation (e.g., administrative or operational error).

The remaining nine types of defects were dismissed from further analysis on various grounds (SAR Section 2.3.6.8.4.3.1) as described below:

As part of the fabrication process, drip shield welds will be inspected using a variety of examination methods (SAR Table 1.9-9, design control parameter 07-10). Welds in the drip shield will be stress-relieved through heat treatment (SAR Table 1.9-9, design control parameter 07-13); therefore, any flaws remaining after the inspections will not be sources for propagation of cracks. Thus, weld flaws in the drip shield are screened from further evaluation.

The drip shield is not low-plasticity burnished, and therefore failure of this operation does not need to be considered for drip shield early failure.

Handling or installation damage of the drip shield is not considered further as it is expected to result in stress corrosion cracking, which is excluded on the basis of low consequence as discussed in excluded FEP 2.1.03.02.0B, Stress Corrosion Cracking (SCC) of Drip Shields (SNL 2008, FEP 2.1.03.02.0B).

Improper weld-flux material, poor weld-joint design, missing welds, contaminants, and mislocated welds are not analyzed further based on a similar rationale as given above for the waste package outer corrosion barrier.

For each type of defect of the waste package or the drip shield retained for further analysis, an event tree was created and the reliability of key processes associated with the formation, detection, and/or repair of these defects was identified and assigned probabilities of failure. For example, for improper base metal selection to impact performance, first an improper base metal must be selected and then not detected by a technician (SNL 2007, Section 6.3.2). Similar treatments are carried out for the other defect types analyzed.

In summary, the approach taken for the evaluation of waste package and drip shield early failure is to evaluate industrially relevant analogues (e.g., boiler and pressure vessels, nuclear fuel rods) to identify the types of defects which can potentially affect waste package or drip shield performance and then evaluate these types of defects for applicability to the repository system. The approach to constructing the event sequences involved identification of key processes and assignment of probabilities of success and failure of these processes. This approach is adequate and appropriate for the reasons described below.

As discussed in SAR Section 2.3.6.6.3.2.7, the overall probability of waste package early failure is given by a lognormal distribution with a mean value per waste package of 1.13×10^{-4} and an error factor of 8.17. These estimated early failure probabilities are similar to failure rates of boilers, pressure vessels, nuclear fuel rods, underground storage tanks, radioactive cesium capsules, and SNF dry storage casks (SAR Section 2.3.6.6.4.2). The failure rates used to compare to the overall probability of waste package early failure are based on historical error rates, which include contributions from nominal human actions (Part (b) of the RAI), and do not account for more recent improvements made in fabrication methods, processes, procedures, and human factors and are therefore higher than would be expected for the waste packages and drip shields (SAR Section 2.3.6.6.4.2). Therefore, the early failure probabilities for waste packages are consistent with historical failure probabilities which include the effects of nominal human actions.

As discussed in SAR Section 5.3, industry accepted codes and standards and regulatory guidance documents related to the training of personnel will be used in repository operations and waste package and drip shield fabrication. As discussed in SAR Section 5.6, plans and procedures for operations, maintenance, surveillance, and periodic testing of structures, systems, or components and processes used in waste package handling, including procedural safety controls, will be written, tested, and approved prior to receipt of waste. Thus, it is reasonable to expect that waste package and drip shield handling and emplacement will be accomplished at a pace that is comfortable for the operator and without competing demands for the operator’s attention during the process steps. The level of stress on the operator during these operations is expected to be low. In addition, stringent quality assurance requirements will be imposed upon waste package and drip shield fabricators through the Project’s quality assurance program. These requirements will be similar to standard nuclear industry practices for safety related items and equipment. This is demonstrated as discussed in SAR Section 1.5.2 and 1.3.4 in that the waste package and drip shields will be fabricated in accordance with *2001 ASME Boiler and Pressure Vessel Code* (ASME 2001, Section III, Division 1, Subsection NC). The contribution from nominal human actions (i.e., those that do not lead directly to waste package and drip shield defects) is expected to be significantly lower than those from the key processes identified, as demonstrated by the comparison to industrial analogues discussed above.

Therefore, by evaluation of industrially relevant analogues (e.g., boiler and pressure vessels, nuclear fuel rods) to identify the types of defects which can potentially affect waste package or drip shield performance and then evaluating these types of defects for applicability to the repository system, an appropriate analyses was performed. This is demonstrated by the favorable comparison of estimated early failure rates to historical failure rates. Furthermore, the treatment of the consequences of waste package early failure processes is identified as one of the key conservatisms used to assess barrier capability in the Yucca Mountain Safety Analysis Report (SAR Section 2.3.6.9.3). The entire surface area of an early failed waste package is considered to be completely failed at the time of repository closure, even though the failure mechanism would not be expected to impact the entire surface area or have impact at the time or repository closure (SAR Section 2.3.6.6.1). This conservatism in considering the entire surface area to be completely failed increases the area for radionuclide transport from the early failed waste packages.

Similarly, as discussed in SAR Section 2.3.6.8.4.1, within the TSPA, drip shield early failure is represented as loss of 100% of the functionality of the drip shield at the time of repository closure. The most likely effect of manufacturing defects would be early onset of stress corrosion cracking, which has been screened from TSPA (SAR Section 2.2, Table 2.2-5, FEP 2.1.03.02.0B). Furthermore, as a bounding assumption in TSPA (SAR Section 2.4.1.2.2), the waste package under an early-failed drip shield is assumed to experience localized corrosion over its entire surface as soon as seepage contacts the waste package.

In spite of the conservative treatment of the consequences of waste package and drip shield early failure processes, from a risk-informed perspective, waste package and drip shield early failure processes are minor contributors to the calculated mean annual dose. As discussed in SAR Section 2.4.2.2.1.2, mean annual doses calculated for both the 10,000-year and the post-10,000-year time periods are dominated by releases from the seismic ground motion and igneous intrusion modeling cases. Therefore, from a risk-informed perspective, waste package and drip shield early failure processes are minor contributors to the calculated mean annual dose (i.e., the individual protection standard).

As discussed in SAR Section 2.4.4.1.1, the performance measures used to evaluate compliance with the groundwater protection standards are dominated by the seismic ground motion modeling case. As discussed in the response to RAI 3.2.2.1.2.2-003, a sensitivity study, in which the number of waste package early failures was increased by a factor of about three and the number of drip shield early failures was increased by a factor of about ten, showed a negligible impact on compliance with the individual or groundwater protection standards. Therefore, from an overall risk-informed perspective, waste package and drip shield early failure processes have a negligible impact on compliance with the individual or groundwater protection standards.

2. COMMITMENTS TO NRC

None.

3. DESCRIPTION OF PROPOSED LA CHANGE

None.

4. REFERENCES

ASME (American Society of Mechanical Engineers) 2001. *2001 ASME Boiler and Pressure Vessel Code*. New York, New York: American Society of Mechanical Engineers. TIC: 251425.

SNL (Sandia National Laboratories) 2007. *Analysis of Mechanisms for Early Waste Package/Drip Shield Failure*. ANL-EBS-MD-000076 REV 00. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20070629.0002; DOC.20071003.0015; LLR.20080311.0094; DOC.20080918.0002.

SNL 2008. *Features, Events, and Processes for the Total System Performance Assessment: Analyses*. ANL-WIS-MD-000027 REV 00. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20080307.0003; DOC.20080407.0009; DOC.20080722.0002.

RAI: Volume 3, Chapter 2.2.1.2.2, Number 4

Provide a criterion-based definition of what constitutes handling damage of the waste package, which supports the early failure scenario in the performance assessment.

Basis: In SAR, Section 2.3.6.6.3.2.6, DOE defines handling damage as "…visible gouging or denting of the waste package surface that may jeopardize the performance of the Alloy 22 outer corrosion barrier." This definition does not provide a technical basis to determine what level of handling damage may affect the postclosure performance of the waste package, for either the early failure or nominal scenario. Elsewhere (SNL, 2007b), DOE specifies that potential scratches (i.e., removal of material) should be limited to a depth of 1.6 mm, and dents (i.e., displacement of material without removal) should have a width of at least five times the depth. There is no clearly specified technical basis that demonstrates potential damage at or below these thresholds would not affect performance significantly, or determines that damage at or exceeding these thresholds would result in conditions used for the early failure scenario in the performance assessment.

RAI References

SNL 2007b. Total System Performance Assessment Data Input Package for Requirements Analysis for DOE SNF/HLW and Naval SNF Waste Package Overpack Physical Attributes Basis for Performance Assessment. TDR-TDIP-ES-000009 REV 00. Las Vegas, Nevada: Sandia National Laboratories.

1. RESPONSE

The criterion-based definition of handling damage is specified in Design Control Parameters 03-18, Waste Package Surface Marring Prior to Emplacement, and 03-24, Waste Package Surface Damage Prior to Closure (SAR Table 1.9-9). The text related to Design Control Parameter 03-18 reads:

> The waste package shall be certified as suitable for emplacement by process control and/or inspection to ensure surface marring is acceptable per derived internal constraint. The surface marring constraints are (1) the damage to the waste package outer corrosion barrier that displaces material (i.e., scratches) shall be limited to 1/16 in. (1.6 mm) in depth; and (2) modifications to the waste package outer corrosion barrier that deform the surface, but do not remove material (i.e., dents), shall not leave residual tensile stresses greater than 257 MPa.

The text related to Design Control Parameter 03-24 reads:

> The emplacement drift ground support system shall be inspected prior to drip shield installation. Waste packages that have come in contact with fallen rock or ground support materials will be inspected to ensure the damage to the waste package outer corrosion barrier that displaces material (i.e., scratches) shall be limited to 1/16 in. (1.6 mm) in depth. Modifications to the waste package outer corrosion barrier that deform the surface, but do not remove material (i.e., dents), shall not leave residual tensile stresses greater than 257 MPa.

The criterion for residual stress damage is 257 MPa residual tensile stress as noted in SAR Table 1.9-9, Design Control Parameter 03-24. DOE is in the process of updating *Total System Performance Assessment Data Input Package for Requirements Analysis for DOE SNF/HLW and Naval SNF Waste Package Physical Attributes Basis for Performance Assessment* (SNL 2007d) to be consistent with the text of Design Control Parameter 03-24.

Surface damage could affect the likelihood and extent of stress corrosion cracking, general corrosion, and localized corrosion. Stress corrosion cracking is evaluated in *Stress Corrosion Cracking of Waste Package Outer Barrier and Drip Shield Materials* (SNL 2007a) and general corrosion and localized corrosion are evaluated in *General Corrosion and Localized Corrosion of Waste Package Outer Barrier* (SNL 2007c).

In *Stress Corrosion Cracking of Waste Package Outer Barrier and Drip Shield Materials* (SNL 2007a, Table 8-15), the stress threshold for the initiation of stress corrosion cracking on the Alloy 22 waste package outer corrosion barrier is defined to be uniformly distributed between 90% and 105% of the yield strength. The Alloy 22 yield strength used in TSPA is 351 MPa. Therefore, the lower bound of the stress threshold distribution for the initiation of stress corrosion cracking on the Alloy 22 waste package outer corrosion barrier is (0.9 × 351 MPa) about 316 MPa. As this value is significantly greater than the 257 MPa residual tensile stress surface damage criterion, there is significant design margin used in the definition of this surface damage criterion.

Furthermore, shallow scratches that are less than or equal to 1/16 in. (1.6 mm or about 6% of the 25-mm thick Alloy 22 waste package outer corrosion barrier thickness (SAR Table 1.9-9, Design Control Parameter 03-03)) in depth are acceptable. Scratches of this depth should not induce tensile through-wall stress profiles due to their limited extent, or appreciably affect the general corrosion performance of the Alloy 22 waste package outer corrosion barrier. In addition, shallow scratches in a ductile material such as Alloy 22 are not expected to be sharp and would not have high stress intensity factors associated with them. Also, general corrosion processes should act to smooth the waste package surface over time, effectively removing scratches.

However, scratches or dents could lead to local areas of cold work. The effect of cold work (e.g., resulting from scratches or dents) on stress corrosion cracking initiation has been evaluated in *Stress Corrosion Cracking of Waste Package Outer Barrier and Drip Shield Materials* (SNL 2007a, Section 6.2.1) by analysis of cold worked and welded constant load specimens, as well as welded and unwelded U-bend specimens. Both welding and the deformation involved in fabricating a U-bend specimen would induce limited amounts of cold work. It was observed that cold worked Alloy 22 specimens were as resistant to stress corrosion cracking initiation as annealed Alloy 22 specimens in that no stress corrosion cracking initiation occurred. The effect of limited amounts of cold work on stress corrosion crack growth is adequately incorporated into the Alloy 22 stress corrosion crack growth rate model as it is based, primarily, on crack growth data from both cold worked and welded specimens (SAR Table 2.3.6-17). The effect of cold work on general and localized corrosion of Alloy 22 was evaluated in *General Corrosion and Localized Corrosion of Waste Package Outer Barrier* (SNL 2007c, Sections 6.3.3 and 6.4.6) by analysis of welded and stress mitigated specimens. Both welding and stress mitigation processes will result in limited amounts of cold work. It was observed that the general and localized corrosion behaviors of Alloy 22 are not significantly affected by limited amounts of cold work. Furthermore, because the entire Alloy 22 waste package outer corrosion barrier is considered to be susceptible to localized corrosion (i.e., crevice corrosion) (SAR Section 2.3.6.4.1), only large, and hence easily detectable, scratches could induce significant cold work to potentially affect the localized corrosion behavior of the waste package outer corrosion barrier. Therefore, scratches that are less than or equal to 1/16 in. (1.6 mm) in depth will not lead to enhancement of stress corrosion cracking, general corrosion, or localized corrosion of the Alloy 22 waste package outer corrosion barrier.

In summary, use of the 257 MPa residual tensile stress surface damage criterion and limitation of scratches to 1/16 in. (1.6 mm) in depth is not expected to lead to enhancement of degradation of the Alloy 22 waste package outer corrosion barrier relative to the nominal scenario.

The possibility of unlikely, undetected, and thus unmitigated events that could damage the waste package outer corrosion barrier is evaluated in *Analysis of Mechanisms for Early Waste Package/Drip Shield Failure* (SNL 2007b). These undetected events include undetected and unmitigated handling damage possibly in excess of the criteria specified in Design Control Parameters 03-18 and 03-24 (SAR Table 1.9-9). As discussed in the response to RAI 3.2.2.1.2.2-001, the consequences of the Alloy 22 waste package outer corrosion barrier early failure processes are treated in a conservative manner. The entire surface area of an early failed waste package is considered to be completely failed at the time of repository closure, even though the failure mechanism would not be expected to impact the entire surface area or have an immediate impact on waste package performance. In this context, enhancement of degradation of the Alloy 22 waste package outer corrosion barrier relative to the early failure scenario is conservatively, yet appropriately, evaluated.

2. COMMITMENTS TO NRC

None.

3. DESCRIPTION OF PROPOSED LA CHANGE

None.

4. REFERENCES

SNL (Sandia National Laboratories) 2007a. *Stress Corrosion Cracking of Waste Package Outer Barrier and Drip Shield Materials*. ANL-EBS-MD-000005 REV 04. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20070913.0001; LLR.20080311.0084; LLR.20080408.0242.

SNL 2007b. *Analysis of Mechanisms for Early Waste Package/Drip Shield Failure*. ANL-EBS-MD-000076 REV 00. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20070629.0002; DOC.20071003.0015; LLR.20080311.0094; DOC.20080918.0002.

SNL 2007c. *General Corrosion and Localized Corrosion of Waste Package Outer Barrier*. ANL-EBS-MD-000003 REV 03. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20070730.0003; DOC.20070807.0007; LLR.20080414.0018.

SNL 2007d. *Total System Performance Assessment Data Input Package for Requirements Analysis for DOE SNF/HLW and Naval SNF Waste Package Physical Attributes Basis for Performance Assessment.* TDR-TDIP-ES-000009 REV 00. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20070921.0009; LLR.20080328.0007.

RAI: Volume 3, Chapter 2.2.1.2.2, Number 6

Describe follow-up actions that will be taken if damage to the waste package is remotely detected with the camera, and justify the expected reliability of such actions, if warranted.

RAI Basis: In SNL (2007a), as referenced in SAR, Section 2.3.6.6.3.2.6, DOE does not describe actions that will be taken if damage to the waste package that may occur during emplacement is visually detected. If DOE relies on the likelihood of damage correction to support the postclosure performance assessment, then the technical basis should be developed for the corrective actions and associated reliabilities of such actions.

RAI References:

SNL (Sandia National Laboratories). 2007a. Analysis of Mechanisms for Early Waste Package/Drip Shield Failure. ANL-EBS-MD-000076 REV 00. Las Vegas, Nevada: Sandia National Laboratories.

1. RESPONSE

1.1 INSPECTION, RECOVERY AND REPAIR OF A WASTE PACKAGE

Should waste package surface damage be discovered during camera inspection of a waste package, whether during emplacement, postemplacement, or closure operations, the waste package will be retained in or returned to a surface facility for repair, as appropriate. Following repair the waste package would be re-emplaced.

Following waste package welding and prior to emplacement, examination of the waste package surface includes inspection of the exterior of the waste package during the transition of the waste package from the waste package transfer trolley to the transport and emplacement vehicle (TEV), with the use of high resolution cameras. The surface area obscured by the pallet during this transition is not inspected. This is because the waste package is inspected for defects and finish at several stages of production and prior to delivery to the process facilities and placement on the pallet.

At the time of repository closure, the final inspection is performed by a remotely operated inspection gantry prior to emplacement of the drip shields. The inspection at closure is to determine if ground support has failed or if rock fall has occurred, and to use that criterion to determine if an inspection for waste package surface damage is required. The inspection at closure is only done for waste packages that may have been affected by failed ground support or rock fall during the postemplacement phase. The subsurface facility allows movement of waste packages and recovery of any waste package at any time until closure, so repairs can be performed as needed. Undamaged waste packages would be removed and relocated to an alternate drift by the TEV in reverse sequence to the original emplacement until the damaged waste package is reached.

A decision will be made, depending on the extent of damage to the waste package surface and other considerations, as to whether repair of the outer corrosion barrier or complete replacement of the outer corrosion barrier is appropriate. The TEV will return the damaged waste package to the existing facilities, which have (or alternate facilities which at closure will have) the capabilities and ITS SSCs required for waste package repair activities. The TEV will deliver the waste package on its pallet to the appropriate facility where the surface repair can be performed, and inspected for conformance with the postclosure control parameters. Following repair, the TEV will transport the waste package and pallet back to an emplacement drift.

1.2 RELIABILITIES ASSOCIATED WITH OPERATIONS DESCRIBED IN THIS RESPONSE IN SUPPORT OF POSTCLOSURE PERFORMANCE ASSESSMENT

If a waste package is found to exceed the postclosure design bases damage limitations, a remediation plan will be developed specific to the findings from the inspection. Such remediation may include removal of the damaged waste package for repair or replacement of the damaged outer corrosion barrier. If the Alloy 22 waste package outer corrosion barrier is repaired, the outer corrosion barrier repairs will be inspected for conformance with postclosure control parameters, i.e., the effectiveness of the repair process is evaluated, to ensure the waste package condition is at a minimum equivalent to that of an as-emplaced waste package. Since a repaired waste package would have been subjected to all of the inspection processes of an as-emplaced waste package as well as inspections associated with the repair/remediation process, these extra inspections would decrease the probability of undetected defects in repaired waste packages to values below those expected for as-emplaced waste packages. Further, if repair processes such as surface grinding resulted in limited areas of cold work, no enhanced degradation of the Alloy 22 waste package outer corrosion barrier is expected as discussed in the response to RAI 3.2.2.1.2.2-004.

If the waste package is replaced, the waste package would undergo the same handling processes and inspections as an initially emplaced waste package and would thus have the same probability of damage and damage detection. In summary, the replacement of the waste package has the same or lower probability of damage as an initially emplaced waste package.

As shown in the response to RAI 3.2.2.1.2.2-002, the probability of waste package handling damage (referred to as handling error in Table 1 of the response to RAI 3.2.2.1.2.2-002) is a minor contributor to the overall probability of waste package early failure. Thus, the follow-up actions that will be taken if damage to the waste package is detected would have a minor impact on overall repository performance.

2. COMMITMENTS TO NRC

None.

3. DESCRIPTION OF PROPOSED LA CHANGE

None.

RAI: Volume 3, Chapter 2.2.1.2.2, Number 8

Provide additional justification for the calculated probability of drip shield emplacement failure.

Basis: The only emplacement error that DOE identified for the drip shield is improper interlocking between adjacent plates such that there is a gap (SNL 2007a, as referenced in SAR, Section 2.3.6.8.4.3.2.4). DOE intends to use a camera to remotely monitor the emplacement of drip shields. Concerns about how this action will be reliably estimated are contained in RAI 5. Additionally, each event in the DOE event sequence that leads to improper drip shield emplacement is a human error event. DOE apparently assumes that no equipment or mechanical errors will occur during drip shield emplacement. This assumption should be supported by a technical basis that demonstrates mechanical or equipment reliability is not a significant component of the drip shield emplacement failure analysis.

RAI References:

SNL (Sandia National Laboratories). 2007a. Analysis of Mechanisms for Early Waste Package/Drip Shield Failure. ANL-EBS-MD-000076 Rev 00. Las Vegas, Nevada: Sandia National Laboratories.

1. RESPONSE

As described in SAR Section 2.3.6.8.4.3.2.4, the only emplacement error identified for the drip shield is improper interlocking between adjacent drip shields such that there is a gap. DOE intends to use a camera to remotely monitor the emplacement of drip shields. This response to RAI 3.2.2.1.2.2-008 provides:

1. Additional justification for the probability value of a camera not detecting improper interlocking between adjacent drip shields
2. Demonstration that mechanical or equipment reliability is not a significant component of the drip shield emplacement failure analysis.

1.1 MANIFESTATION OF IMPROPER INTERLOCKING OF DRIP SHIELDS

As described in SAR Section 1.3.4.7.1,

> The drip shield sections are designed to accommodate an interlocking feature to prevent separation between the contiguous segments. This feature consists of an overlapping section with connector guides between the drip shield segments. The minimum lift height required to interlock the drip shield segments is 40 in. for clearance between the two drip shield segments. The drip shield base plates rest on the transverse support beams of the drift invert and inside of the rail runway beams.

> The drip shield is designed so that, when in its position, it does not contact the emplacement pallet, the waste package, or the rail runway beams (Figure 1.3.4-4).
>
> Details of the drip shield interlocking features and the assembly are shown in Figures 1.3.4-14 and 1.3.4-15. An isometric view of the drip shield is provided in Figure 1.3.4-14.

Misalignment of adjacent drip shields would result if the drip shield connector guide on the outer surface of one drip shield was not correctly placed underneath the drip shield connector plate on the adjacent drip shield (SAR Figure 1.3.4-14). Thus, misplacement would result in the drip shield connector guide being visible to the inspection camera, if the drip shields were placed too far apart, or in the elevation of the overlying drip shield by at least 65 mm (SAR Table 1.3.4-3), if the drip shields were placed too close together and the overlying drip shield is incorrectly resting atop the drip shield connector guide. Either error would be readily manifest to the inspection camera, which will be selected to provide sufficient resolution of the drip shield interlocking mechanism.

1.2 JUSTIFICATION FOR PROBABILITY OF NON-DETECTION OF IMPROPER INTERLOCKING

Proper interlocking of adjacent drip shields will be monitored remotely by high-resolution cameras (SAR Section 1.3.4.7.2). Given that the camera operates correctly, interpretation of the display resulting from a camera inspection of the drip shield connections can be modeled by an operator monitoring a visual display on which the view of correctly connected drip shields is the normal condition. Failure of this inspection occurs when the operator fails to note a deviant condition on the display (i.e., incorrectly connected drip shields); thus, classifying this error as an error of commission is appropriate. Moreover, monitoring the analog visual display for deviant conditions is similar to monitoring an analog meter for a reading within acceptable limits, because no quantitative information is recorded, and because the operator will examine more closely any apparent deviation from the normal condition (i.e., gaps, unexpected view of components of a drip shield that should be occluded from view, etc.). Thus, “check-reading of an analog meter” is an appropriate model for the probability of human error in the inspection process during emplacement, and this probability is characterized by the distribution given in Swain and Guttmann (1983, Table 20-11, Item 3) (i.e., check-reading of an analog meter with difficult-to-see limit marks).

As indicated in SAR Table 1.3.4-5, Parameter Number 07-14, drip shields

> …shall be handled in accordance with standard nuclear industry practices to minimize damage, surface contamination, exposure to adverse substances, and impacts. Drip shield installation shall be controlled and monitored through appropriate equipment to minimize possible waste package/drip shield damage and/or misinstallation. Installation shall include the use of equipment with an alarm, an operator, and an independent checker. Records demonstrating compliance shall be maintained.

Because the handling of the drip shields will be accomplished under stringent controls (SAR Table 1.9-9, drip shield design control parameters), drip shields will be individually inspected at a pace that is comfortable for the operator and without competing demands for the operator's attention during the inspection. Thus, the level of stress on the operator during the inspection is expected to be low, and no performance-shaping factors are applied to the selected distribution.

1.3 EFFECT OF EQUIPMENT RELIABILITY DURING EMPLACEMENT

Proper interlocking of adjacent drip shields will be monitored remotely by high-resolution cameras (SAR Section 1.3.4.7.2). In addition to the camera, drip shield alignment is also monitored by means of an alarm system that will be developed to detect misalignment and alert the operator (SAR Table 1.3.4-5, Parameter Number 07-14). Thus, equipment failure would allow misalignment of a drip shield to remain undetected only if both the camera and the alarm system malfunctioned, and both the operator and the checker failed to detect malfunction of the equipment. Figure 1 illustrates an event tree estimating the probability of failure to achieve proper interlocking of adjacent drip shields which adds events describing equipment reliability to the fault tree presented in Figure B-22 of *Analysis of Mechanisms for Early Waste Package/Drip Shield Failure* (SNL 2007). Figure B-22 of that report (SNL 2007) considered only events related to human error as potentially leading to improper emplacement of the drip shield. For ease of comparison of Figure 1 with Figure B-22, the event sequence leading to the damaged drip shield end state that is common to both figures is highlighted.

Faults in the camera (mechanical or other) could affect the rate of error in the inspection of drip shields during emplacement. For the purpose of this response, the probability of a camera fault is conservatively selected to be 0.01 per drip shield installation. Current technology produces complex electro-optic systems including high-resolution cameras with mean time between failures (MTBF) for the system exceeding thousands of operating hours (Jane's Electro-Optic Systems, available online at http://jeos.janes.com/public/jeos/index.shtml).

It is reasonable to expect an operator to detect and correct any fault that would prevent the camera from imaging the drip shield or which results in an obviously incorrect image. It is also reasonable to expect that, as part of the operating procedure for the inspection, the operator would check the camera display against a known image or calibration target to verify correct camera function. Thus, the camera faults that may affect inspection of the drip shield are those which result in display of an incorrect image which the operator fails to notice is incorrect. Because the handling of the drip shield will be accomplished under stringent controls (SAR Table 1.3.4-5, Parameter Number 07-14), it is reasonable to expect that an operator who notes an incorrect image on the camera display would take steps to address the fault and to obtain a correct image. Therefore, operator failure to recognize a camera fault can be modeled as "check-reading of an analog display" without any performance-shaping factors (i.e., mean failure probability of 2.5×10^{-3}, from Swain and Guttman 1983, Table 20-11, Item 3). In summary, the occurrence of undetected faults in the camera is quantified by scaling the distribution given in Swain and Guttmann (1983, Table 20-11, Item 3) (i.e., check-reading of an analog meter with difficult-to-see limit marks) by the probability of a camera fault occurring during installation of a drip shield to obtain a mean probability of 2.5×10^{-5}.

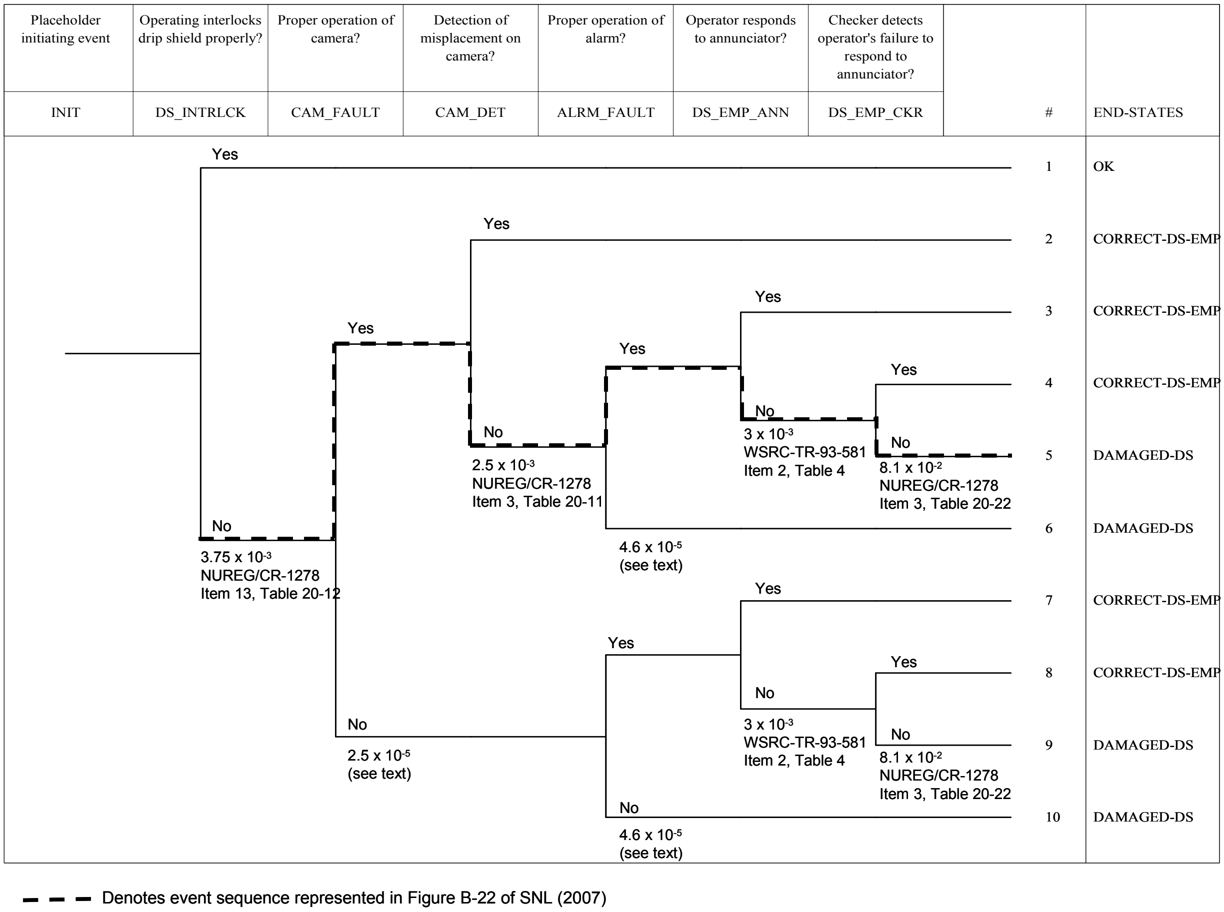

Figure 1. Alternate Event Tree for Evaluating Improper Emplacement of the Drip Shield

Drip shield alignment is also checked via an alarm system (SAR Table 1.3.4-5, Parameter Number 07-14.) If the alarm system operates correctly, misalignment could be undetected only if both the operator and checker fail to notice the alarm indicator. These possibilities are accounted for in the estimate of the probability of drip shield by events DS_EMP_ANN and DS_EMP_CKR, respectively, in Figure B-22 of *Analysis of Mechanisms for Early Waste Package/Drip Shield Failure* (SNL 2007).

Faults in the alarm system may prevent detection of improperly interlocked drip shields that are also undetected by the camera. For the purpose of this response, the probability of alarm system malfunction is conservatively selected to be 0.01 per drip shield installation. An analysis quantifying mean time between failure (MTBF) for the alarm system would require detailed design of the alarm system and is not necessary for this estimate. The conservative estimate of failure of 0.01 per drip shield installation is justified because component failure rates on the order of 1 per 100,000 operating hours are reported for sensor and instrumentation systems in industry applications (IEEE 1984, Section 8.19).

It is reasonable to expect that, as part of the operating procedure for drip shield installation, the alarm system would be tested for correct function. For the purpose of this response, the probability of mechanical failure of the alarm system test such that a malfunctioning alarm system is reported as normal is conservatively selected to be 0.01 per drip shield installation. Because the handling of the drip shield will be accomplished under stringent controls (SAR Table 1.3.4-5, Parameter Number 07-14), it is reasonable to expect that an operator who detects a fault in the alarm system would take steps to address the fault. Therefore, alarm system malfunctions could permit misalignment to remain undetected only if the operational test of the alarm indicates failure and the operator fails to recognize the error, or if the test indicates normal operation of a malfunctioning alarm system and the operator fails to recognize a malfunction of the alarm test. Operator failure to recognize a detected alarm fault can be characterized as failure to respond to a compelling signal (Benhardt et al. 1994, Table 3, Item 2), which can be modeled with a mean failure probability of 3×10^{-3} per demand. Operator failure to recognize a malfunction of the alarm system test can be modeled by Swain and Guttman (1983, Table 20-10, Item 7) (i.e., failure to recognize that an instrument being read is jammed), which provides a median error probability of 0.1 per demand with an error factor of 5, which equates to a mean probability of 0.16 per demand. Thus, the mean probability of an undetected fault in the alarm system is estimated as:

$$p_A \times \left((1 - 0.01) \times 3 \times 10^{-3} + (0.01) \times 0.16 \right) = \left(4.6 \times 10^{-3} \right) \times p_A$$

where p_A is the probability of a fault in the alarm system (assumed to be 0.01 for the purpose of this response). Thus, the mean probability of an undetected fault in the alarm system is estimated as 4.6×10^{-5} per drip shield installation.

Evaluation of the event tree shown in Figure 1 yields a mean probability of improper emplacement of the drip shield of 2.7×10^{-9} per drip shield, an increase over the probability of 2.19×10^{-9} (Table 1 in DOE's response to RAI 3.2.2.1.2.2-002) that results from the event tree presented in Figure B-22 of *Analysis of Mechanisms for Early Waste Package/Drip Shield Failure* (SNL 2007). Improper drip shield emplacement is one of four possible event sequences that contribute to the overall probability of drip shield early failure. Table 1 in DOE's response to RAI 3.2.2.1.2.2-002 provides values for all four event sequences. If the increase in the probability of improper drip shield emplacement due to the possibility for equipment failure were included, the sum of the mean probabilities over all event sequences would not change from 2.22×10^{-6}. Thus, inclusion of the possibility of equipment failure has a negligible effect on the analysis of early failures reported in *Analysis of Mechanisms for Early Waste Package/Drip Shield Failure* (SNL 2007).

2. COMMITMENTS TO NRC

None.

3. DESCRIPTION OF PROPOSED LA CHANGE

None.

4. REFERENCES

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