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U.S. Nuclear Regulatory Commission
ATTN: Dr. James Rubenstone
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Subject: Transmittal of Revised Intermediate Milestone: Review of Analysis of Mechanisms for Early Waste Package and Drip Shield Failure, IM 06002.01.322.630

Reference: Letter dated October 19, 2006, from D. Galvin to Y.-M. Pan, Degradation of Engineered Barriers Intermediate Milestone 06002.01.322.630: Review of Analysis of Mechanisms for Early Waste Package and Drip Shield Failure

Dear Dr. Rubenstone:

Enclosed is the revised intermediate milestone that is identified as 06002.01.322.630 in the Center for Nuclear Waste Regulatory Analyses (CNWRA) Program Manager's Periodic Report for Period 11 fiscal year 2006. The report was revised to address U.S. Nuclear Regulatory Commission (NRC) comments. In addition to the revisions to the report, detailed responses to the NRC comments and questions are attached. We thank the NRC staff for their thoughtful comments.

The report addresses possible mechanisms for early failure of waste packages and drip shields, which may allow water ingress into the failed waste package and lead to early release of radionuclides. In particular, this report reviews the early failure analysis of the waste package outer container and drip shield related to manufacturing-induced defects presented in the U.S. Department of Energy (DOE) report titled Analysis of Mechanisms for Early Waste Package/Drip Shield Failure.

This review of the DOE report indicates that various thermal and mechanical loadings may generate stress states where principal tensile stress can be in any direction. Consequently, cracks of all orientations should be considered in evaluating potential early failure. This review also indicates that nonuniform heating and cooling during heat treatment may alter the microstructure and corrosion resistance of the waste package outer container.

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Therefore, the event tree analysis should include the probabilities that the heating and cooling characteristics and the subsequent heat-treated waste packages do not meet specifications. Overall, the DOE model for weld flaws and calculations of defect characteristics are appropriate.

If you have any questions regarding this deliverable, please contact me at (210) 522–6640.

Sincerely,

Yi-Ming Pan, Ph.D.
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YMP:jg

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Attachment: Center for Nuclear Waste Regulatory Analyses (CNWRA) Responses to U.S. Nuclear Regulatory Commission (NRC) Staff Comments on Intermediate Milestone (IM) 06002.01.322.630 Review of Analysis of Mechanisms for Early Waste Package and Drip Shield Failure

General Comments

1. *This report basically evaluates U.S. Department of Energy (DOE) early failure analysis of the waste package outer container and drip shield due to manufacturing or handling-induced defects. The report concludes that the DOE's assessment is correct. When this assessment is used in the TPA model abstraction, it is recommended to consider all previous related reports (NRC IM 06002.01.081.310, LSN NRC 000026343, 2003; ADAMS ML031840693). Previous reports extended their studies to include various engineering systems. The TPA4 model abstraction was based on the previous reports. The TPA5 model abstraction may consider this new evaluation only partly if the TPA4 model abstraction needs to be modified.*

Response:

The current initially defective fraction range in TPA 4.1 is a uniform distribution of 1.0e-4 and 1.0e-2. For the current number of 12,177 waste packages in the repository, it translates to a lower bound of approximately 1 defective waste package, and an upper bound of 122 waste packages (1 out of 100 waste packages). The range was estimated using analogous data from previous NRC reports, including NRC IM 06002.01.081.310, (LSN NRC 000026343, 2003; ADAMS ML031840693) and Tschoepe III, et al., 1994 (ADAMS ML033650222). The range was not changed in TPA 4.1. It is recommended, however, to change the distribution to log-uniform to highlight lower values of the range.

The DOE nominal case analysis of waste package and drip shield degradation (Bechtel SAIC Company, LLC, 2004a) considers a distribution to sample the recurrence rate of early waste package failure. With the recurrence rate and a Poisson distribution, the number of initially failed waste packages in a realization is determined. The recurrence rate considered in the DOE analysis is on the order of approximately 10^{-5} per waste package; thus, if roughly 10,000 waste packages are emplaced, approximately 0.1 waste package is expected to be initially defective. The document Analysis of Mechanisms for Early Waste Package/Drip Shield Failure reports a mean value of 3×10^{-5} per waste package occurrence rate (Bechtel SAIC Company, LLC, 2004b).

In the recent technical exchange, DOE stated they will apply strict fabrication process control to minimize the occurrence of defects. It is possible that the defective fraction can be further reduced when better inspection or better welding technology are applied. We can update or change the number when new process data from DOE are available.

References:

Bechtel SAIC Company, LLC. "WAPDEG Analysis of Waste Package and Drip Shield Degradation." ANL–EBS–PA–000001. Rev. 02. Las Vegas, Nevada: Bechtel SAIC Company, LLC. 2004a.

———. "Analysis of Mechanisms for Early Waste Package/Drip Shield Failure." CAL–EBS–MD–000030. Rev. 00C ICN00. Las Vegas, Nevada: Bechtel SAIC Company, LLC. 2004b.

Tschoepe III, E., F.F. Lyle, Jr., D.M. Dancer, C.G. Interrante, and P.K. Nair. "Field Engineering Experience With Structural Materials." San Antonio, Texas: CNWRA. 1994.

2. *In SUMMARY, the author listed main findings. Regardless of these findings, the last bullet states that the calculation is correct. It is unclear whether this means the mathematical treatment is correct or the total assessment is reasonable regardless of the findings listed.*

Response:

The author independently verified the mathematical calculations using Mathcad, and they proved to be correct. No statement was made as to whether the assumptions behind the Mathcad computations were correct. The areas where the author agreed with the DOE assessment and the areas of uncertainties were already pointed out in the summary of the report.

Specific Comments

3. *In p. 1-1, the first paragraph, disruptive events were mentioned for loading. What kind of disruptive events are considered?*

Response:

Disruptive events include seismic, faulting, rockfall, and dike intrusion events. Text was added in the revised version of the report.

4. *In the first paragraph under Heat Treatment Variability, it is stated that local residual stress can exceed the permissible average value. Are there any data on it?*

Response:

Residual stress data on welded plates have been reported by DOE (Bechtel SAIC Company, LLC, 2003). The local residual stress data after solution treatment for the Alloy 22 waste package outer barrier, however, do not exist at this time. A prototype waste package heat treatment was performed by DOE at Joseph Oat on July 21, 2006. Extensive characterization and measurements of localized residual stresses are planned for the prototype by DOE.

References:

Bechtel SAIC Company, LLC. "Technical Basis Document No. 6: Waste Package and Drip Shield Corrosion. Appendix B. Distribution of Stresses." Las Vegas, Nevada: Bechtel SAIC Company, LLC. 2003.

5. *In p. 2-7, the top paragraph, it indicated nonuniform heating and cooling. What would this imply in terms of reliability?*

Response:

Text on the implications of nonuniform heating and cooling was added to the revised version of the report. The heat treatment process is a critical fabrication step intended to remove any residual stresses from fabrication. The heat treatment processes introduce compressive surface stresses to delay the onset of stress corrosion cracking. Nonuniform heating and cooling can cause formation of precipitates in the welds. These inhomogeneities are the potential sites for localized corrosion and initiation of stress corrosion cracking. Reliability can be compromised as a result of nonuniform heating and cooling.

6. *In p. 2-8, in the paragraph beginning "There is not....." the stress relaxation is mentioned. Does this mean that the assessment here is conservative?*

Response:

DOE has not evaluated the stability of residual stress by combined thermal and mechanical loading. Therefore, the DOE approach was not conservative.

7. *In p. 2-9 to 2-13, are these formula generally applicable to Ti [titanium] too?*

Response:

In the Bechtel SAIC Company, LLC, report, it was assumed that the flaw size and density distributions in titanium are the same as those of Alloy 22 (see assumption 5.8.1). Therefore, the same equations are used. These are described in Section 6.31 (p. 89) of the Bechtel SAIC Company, LLC, report.

8. *In p. 2-14, the second paragraph, the detection limit is addressed ("nondetection increases rapidly as the depth approaches zero"). Are there quantitative thresholds on the detection limit?*

Response:

The review report addresses the reliability of two ultrasonic inspection techniques (i.e., conventional pulse-echo ultrasonic technique and Raleigh wave technique). The inspection procedure using Raleigh wave (or surface wave) allows near surface inspection with high sensitivity and reproducibility. The quantitative measures of these techniques, however, are not known to the reviewer.

9. *In p. 2-17, after the first equation, a difference of two orders of magnitude is mentioned. How does this affect the conclusion of this report?*

Response:

Without installation of thermocouples to validate the temperatures, nonuniformity and variability in heat treatment processes are of concern. The frequency of improper heat treatment of the

waste package can increase significantly. This was pointed out as one of the major findings of the review.

10. *Reviewer makes good observations that: (a) human performance is likely to be an important contributor to early WP/DS [waste package/drip shield] failures (p. 2-17), (b) potential dependencies in the sequence of human errors warrant further attention (p. 2-17), and (c) the operator may fail to detect or disclose waste packages that do not meet specifications. These are all important observations of potential shortcomings in the subject BSC [Bechtel SAIC Company, LLC] report that was reviewed.*

Response:

Human performance, human errors, and operator errors are important potential contributors for defective parts in waste packages and drip shields. The comment is appreciated.

11. *In addition, the reviewer and other consumers of this report should be aware of the limitations of THERP, the method used in the BSC report to quantify human errors, and potential shortcomings in the application of THERP to these event sequences. NUREG–1842 [Ref. 1] provides good guidance on reviewing the use of THERP {and other HRA [human reliability analysis] methods} in an application (companion document NUREG-1792 [Ref. 2] outlines good practices for HRA; note that both of these NUREGs were developed for at-power internal event PRAs [probabilistic risk assessment] for nuclear power plant applications, but also contain good general guidance for evaluating other HRA applications). For example, "THERP focuses primarily on rule-based behavior, in which operators follow procedures... THERP also treats diagnosis [human failure events] via a time-reliability correlation" [1]. Are the human errors modeled here rule-based/procedure-based actions, or diagnosis tasks dominated by dependent on how much time is available? If not, is it appropriate to use error probabilities from the THERP tables? As another example, one of the "helpful hints" for THERP in NUREG–1842 directs reviewers to look for documentation of the underlying task analysis, including HRA event trees (to the extent used), and reminds reviewers that it is inappropriate to select human error probabilities from THERP tables without an appropriate supporting task analysis. Was there evidence of such a task analysis in the BSC report reviewed? If not, what is the technical justification in the report that the human errors chosen, and the associated error probabilities assigned, are appropriate to this application? How would dependencies among potential human errors in the same event sequence be taken into account? Also, in general, the use of methods and data developed for NPP [nuclear power plant] operations should be justified when applied to non-NPP applications.*

References

[1] U.S. NRC, Evaluation of Human Reliability Analysis Methods Against Good Practices, Final Report, NUREG–1842, September 2006.

[2] U.S. NRC, Good Practices for Implementing Human Reliability Analysis (HRA), Final Report, NUREG–1792, April 2005.

Additional text and two references were added in the revised version of the report. The questions are answered in five parts.

(a) Question: Are the human errors modeled here rule-based/procedure-based actions, or diagnosis tasks dominated by dependent on how much time is available?

Response:

The procedures have not been written and a decision has not been made on the equipment that will be used. Therefore, in the absence of written procedures, assumptions were made about the process. In some of the discussions in Section 6.2.4 (Bechtel SAIC Company, LLC, 2004b), reference is made to the technician failing to use a written procedure, which indicates that human errors are being modeled as procedure-based actions.

(b) Question: If not, is it appropriate to use error probabilities from the THERP tables?

Response:

Justification for using the human error probabilities is discussed in Section 4.1.2 (Bechtel SAIC Company, LLC, 2004b). A comparison is made to the use of this technique in other industries that have highly controlled environments with strict quality standards and controls. Because the technique has been used in these other industries and waste package and drip shield fabrication operations would have similar characteristics, the values are applicable.

(c) Question: As another example, one of the "helpful hints" for THERP in NUREG–1842 directs reviewers to look for documentation of the underlying task analysis, including human reliability analysis event trees (to the extent used), and reminds reviewers that it is inappropriate to select human error probabilities from THERP tables without an appropriate supporting task analysis. Was there evidence of such a task analysis in the Bechtel SAIC Company, LLC, report reviewed?

Response:

Assumptions were made about the process, but no task analysis was performed because the procedures have not been developed and the equipment has not been identified. There is no evidence that a task was broken down into individual steps that were analyzed in detail as part of a task analysis.

(d) Question: If not, what is the technical justification in the report that the human errors chosen, and the associated error probabilities assigned, are appropriate to this application?

Response:

There is no technical justification other than what is included in Section 4.1.2 (Bechtel SAIC Company, LLC, 2004b).

(e) Question: How would dependencies among potential human errors in the same event sequence be taken into account?

Response:

Section 6.2.4 (Bechtel SAIC Company, LLC, 2004b) indicates that dependent events were accounted for in the event tree by assigning them to the same correlation class. It does not indicate that a detailed assessment of dependence was performed. In Section 2.2.3 (Tszeng, 2006), the reviewer indicates that the underlying models of dependency in human reliability analysis may warrant further attention.

References:

Bechtel SAIC Company, LLC. "Analysis of Mechanisms for Early Waste Package/Drip Shield Failure." CAL–EBS–MD–000030. Rev. 00C ICN 00. Las Vegas, Nevada: Bechtel SAIC Company, LLC. 2004b.

Tszeng, T. "Review of Analysis of Mechanisms for Early Waste Package and Drip Shield Failure." San Antonio, Texas: CNWRA. 2006.

12. *p. 2-16, what are the units for the frequencies discussed (e.g., improper heat treatment for the WP frequency is $1.6x10^{-5}$)? Is that the frequency per year, per week, ...? Please spell out.*

Response:

The word "frequency" implies a pointwise estimate; the unit is "per waste package." That is to say, the "frequency" times the number of waste packages is an estimator of the expected number of waste packages with improper heat treatment. The text was modified in the revised report.