REVIEW BY THE U.S. NUCLEAR REGULATORY COMMISSION
OFFICE OF NUCLEAR MATERIAL SAFETY AND SAFEGUARDS
OF THE U.S. DEPARTMENT OF ENERGY AGREEMENT RESPONSES RELATED TO THE POTENTIAL GEOLOGIC REPOSITORY AT YUCCA MOUNTAIN, NEVADA:
WASTE PACKAGE AND DRIP SHIELD CORROSION -RELATED AGREEMENTS UNDER KEY TECHNICAL ISSUES "CONTAINER LIFE AND SOURCE TERM" (CLST 1.07 AND 1.16)

1.0 INTRODUCTION

The U.S. Nuclear Regulatory Commission (NRC) issue resolution goal during this interim prelicensing period is to ensure that the U.S. Department of Energy (DOE) has assembled enough information on a given issue for NRC to accept a license application for a potential geologic repository at Yucca Mountain, Nevada, for review. Resolution by the NRC during prelicensing does not prevent anyone from raising any issue for NRC consideration during the licensing proceedings. It is equally important to note that resolution of an issue by the NRC during the prelicensing period does not prejudge the NRC evaluation of the issue during the licensing review. Issues are resolved by the NRC during prelicensing when the staff have no further questions or comments about how DOE is addressing an issue. Pertinent new information could raise new questions or comments on a previously resolved issue.

By letter dated December 9, 2003, DOE submitted a report titled, "Technical Basis Document No. 6: Waste Package and Drip Shield Corrosion" (Bechtel SAIC Company, LLC, 2003a) to satisfy the informational needs of numerous Key Technical Issue agreement items pertaining to the environmental degradation of the waste package and drip shield materials and to respond to issues raised by the NRC related to corrosion processes and the design of the waste package and drip shield at the potential repository at Yucca Mountain, Nevada. The information was requested by the NRC during previous technical exchanges in September 2000, February 2001, and September 2001. The specific agreements, which are addressed in the Technical Basis Document (TBD), are categorized under three different Key Technical Issues (KTI):

- Container Life and Source Term (CLST) agreements 1.07, 1.12, 1.13, 1.14, 1.15, 1.16, 6.02, and 6.03.
- Repository Design and Thermal Mechanical Effects agreement 3.18.
- General agreement 1.01, Comments 9, 10, 119, and 120.

For all 10 agreements including the 4 comments, DOE stated in the TBD that it has satisfied the NRC information needs regarding the agreements and that all agreements should be considered complete. Section 4.0 of this report provides the NRC evaluation of the extent to which the DOE submittal satisfies the informational requirements of agreements CLST 1.07

Enclosure

and 1.16. The NRC evaluation of the extent to which the DOE submittal satisfies the requirements of the other agreements will be provided in a separate document.

2.0 WORDING OF THE AGREEMENTS

NRC found that the DOE in Appendices A and E of its Waste Package and Drip Shield Corrosion TBD identified CLST 1.07 AIN-1 and CLST 1.16, respectively, as being satisfied by the information provided within the Waste Package and Drip Shield Corrosion TBD. The NRC review of the DOE response to these agreements within the TBD was based on DOE providing the requested information identified in NRC letters, dated October 4, 2001, (ML003760884) for the CLST agreements and dated January 24, 2003 (ML030270065) for the additional information need (AIN). The wording of the agreements and the additional information need include the following.

CLST 1.07: Provide documentation for the alternative methods to measure corrosion rates of the waste package materials (e.g., ASTM G102 testing) or provide justification for the current approach. DOE will document the alternative methods of corrosion measurement in the revision of Alloy 22 AMR (ANL–EBS–MD–000003), prior to License Application.

CLST 1.07, AIN-1: The use of appropriate standards should be adopted and exceptions should be properly justified. If a standard is mentioned but not used in its entirety, DOE should indicate specifically which parts of the standard code will be used (for example, G1 is used for identification of equipment, G1 is used for data interval, etc.). Better justification for not using alternative techniques is needed. If such a justification cannot be provided, then DOE must provide details on the alternative techniques to be used for corrosion rate measurements.

CLST 1.16: Provide the documentation on the measured thermal profile of the waste package material due to induction annealing. DOE stated that the thermal profiles will be measured during induction annealing, and the results will be reported in the next stress corrosion cracking analysis model report (ANL–EBS–MD–000005) prior to License Application.

3.0 TECHNICAL INFORMATION PROVIDED IN THE DOE AGREEMENT RESPONSE

Appendix A of the DOE TBD on Waste Package and Drip Shield Corrosion (Bechtel SAIC Company, LLC, 2003a) provides information related to agreements CLST 1.07 and CLST 1.07 AIN–1. Agreement CLST 1.07 is related to NRC concerns about the lack of a sufficient technical basis for the testing methods used to determine the corrosion rates of the waste package and drip shield materials. CLST 1.07 AIN–1 is related to NRC concerns with DOE not clearly documenting the basis for their testing methods, the adoption of appropriate standards and justification of any exceptions taken to those standards.

The TBD states that the Yucca Mountain Project uses American Society for Testing and Materials (ASTM) C1174 (ASTM International, 1998a) as general guidance and other ASTM International standard methods to develop the database with conservative assumptions for the use of the data for corrosion rate prediction. Validation of the approach involves testing specimens over long periods of time. The corrosion rate of Alloy 22 was measured using more than 100 coupons (specimens) that were exposed for more than 5 years in the Long-Term Corrosion Test Facility at the Lawrence Livermore National Laboratory. The overall corrosion rate obtained after 5 years of immersion was well below 100 nm/yr [3.9×10^{-3} mpy] (Bechtel

SAIC Company, LLC, 2003b; Wong, et al., 2003). The data show the uncertainty in the measured corrosion rate continues to decrease with exposure time as a result of more sensitive measurements, better cleaning procedures, and elimination of the correction for residual silica deposition from the solution.

DOE conducted the immersion tests in accordance with ASTM standards including ASTM G31 (ASTM International, 1999a), ASTM G4 (ASTM International, 2001), and ASTM G1 (ASTM International, 1999b). The main standards used were ASTM G31 and ASTM G1. DOE, in Appendix A to the TBD, identified three exceptions to the standards that include two exceptions to ASTM G31 and one exception to ASTM G1. These exceptions are summarized as follows:

- ASTM G31 (ASTM International, 1999a) recommends the original preparation of the test specimens should be documented to allow interpretation by others. For specimens exposed in the Long-Term Corrosion Test Facility, no scanning electron microscope images were taken to document the initial condition of the test specimens prior to testing. DOE notes that ASTM G 31 does not require scanning electron microscope images from the coupons before testing, but it is now understood as a good practice. Scanning electron microscope images were taken after testing. The post-test examination show no apparent signs of corrosion and grinding marks from the original surface preparation on the test specimens.

- ASTM G31 (ASTM International, 1999a) recommends a testing time that is inversely proportional to the corrosion rate. Tests conducted in the Long-Term Corrosion Test Facility did not follow the recommended testing time. For the corrosion rates measured using specimens exposed in the Long-Term Corrosion Test Facility, the ASTM-recommended testing time would be more than 50 years.

- ASTM G1 (ASTM International, 1999b) recommends using uncorroded coupons to establish a post-test cleaning procedure that does not corrode the base material. Because no uncorroded coupons were available, the post-test cleaning procedure was established using a foil of Alloy 22 with a heat number different from the test coupons. DOE stated that the results obtained by the use of Alloy 22 foils were more accurate than with the use of uncorroded coupons.

Alternative techniques for estimating corrosion rates were also used. These methods were not used to obtain absolute corrosion rate values but to assess changes in the corrosion rates as a consequence of changes in the environment or the metallurgical condition of the alloy. Alternative electrochemical techniques used included:

- Polarization Resistance method according to ASTM G59 (ASTM International, 1998b), and ASTM G102 (ASTM International, 1999c)

- Alternate Current Impedance method according to ASTM G106 (ASTM International, 1999d), and

- Passive current density measurements under constant potential conditions

The results showed that the values of corrosion rates obtained with electrochemical methods corroborate results obtained with the immersion tests.

Appendix E of the DOE TBD on Waste Package and Drip Shield Corrosion (Bechtel SAIC Company, LLC, 2003a) provides information related to agreement CLST 1.16. The agreement is related to the NRC concerns about the lack of sufficient technical basis for the effects of induction annealing of the waste package closure welds on the mechanical properties, residual stress profile, stress corrosion cracking resistance, and localized corrosion susceptibility of the Alloy 22 waste package outer container.

In the TBD (Bechtel SAIC Company, LLC, 2003a), the change in waste package design is referenced. Because the revised waste package design (Bokhari, 2003) does not use induction annealing to mitigate residual stresses in the Alloy 22 outer container closure weld, the thermal profile of the waste package during induction annealing was not provided. The revised waste package design will have two Alloy 22 lids. The outer Alloy 22 lid closure weld stresses will be mitigated by either laser peening or controlled plasticity burnishing. The inner Alloy 22 closure lid weld stresses will not be stress mitigated.

4.0 NRC EVALUATION AND COMMENT

The following sections provide a discussion of the relevance of the agreements to possible repository performance followed by results of the NRC review of the agreement responses, organized by the applicable review methods in the Yucca Mountain Review Plan (YMRP) (NRC, 2003).

4.1 Relevance to Repository Performance

The waste package, composed of the containers and the waste forms, is the primary engineered barrier controlling the release of radionuclides from spent nuclear fuel and high-level waste glass. Because corrosion processes, promoted by the presence of an aqueous environment contacting the surface of the containers, will be the primary cause of container failure under undisturbed conditions, the mode and rate of corrosion need to be evaluated to determine container lifetime. Corrosion processes potentially important in the degradation of the engineered barriers include humid-air and uniform aqueous corrosion, localized (pitting, crevice, and intergranular) corrosion, microbially influenced corrosion, stress corrosion cracking, and hydrogen embrittlement. In addition, dry-air oxidation occurs during the initial period after waste emplacement when the radioactive decay heat keeps moisture away from the gaseous environment surrounding the waste package. Fabrication processes, such as cold working, welding, and postweld heat treatments, may alter the corrosion resistance of the waste package materials. The ability of the waste package to contain radionuclides and limit radionuclide release after any initial penetration is, therefore, determined by the long-term corrosion resistance of the container materials.

Drip shields are a secondary engineered barrier intended to provide an important defense-in-depth function by limiting the amount of dripping water contacting the waste package and limiting damage to the waste package from rockfall. Initiation of aqueous corrosion of the waste packages depends on the deliquescence of dust or the contact with seepage water. The presence of drip shields will delay the contact of seepage water with the waste package surface, resulting in a significantly longer container lifetime. In addition, once the containers are breached, the amount of water available for dissolution of spent nuclear fuel and high-level waste glass and advective transport of the released radionuclides could be limited, even by the presence of a partially damaged drip shield.

4.2 Data and Model Justification

4.2.1 CLST 1.07

Issues related to the measurements of the corrosion rate of the waste package materials discussed in the response to CLST 1.07 are included in the integrated subissue for degradation of engineered barriers. The CLST 1.07 agreement resulted from a staff review of DOE documentation that is consistent with Review Methods 2 in Section 2.2.1.3.1.2 of the YMRP (NRC, 2003). The NRC's review of the response also was conducted in accordance with the aforementioned review method. This review method includes evaluation and confirmation that data used to support the Total System Performance Assessment abstraction are based on appropriate techniques.

The focus of the agreement is on the measurement of corrosion rates of the waste package container materials, appropriateness of the testing methods used to measure the corrosion rates, and evaluation of the measurement uncertainty. The focus of the additional information need is the adoption of appropriate standards for corrosion testing and justifying any exceptions to the standards. The DOE response (Bechtel SAIC Company, LLC, 2003a) identifies that the originally proposed immersion tests will be augmented by alternative methods (electrochemical techniques). The electrochemical techniques will be used to assess changes in corrosion rates as a consequence of changes in the environment or the metallurgical condition of the alloy but not to determine absolute corrosion rate values. DOE has provided an appropriate justification of the electrochemical techniques used and has adopted appropriate standards. DOE does not take any exceptions to the standards for the electrochemical techniques. Therefore, the NRC finds that DOE has provided appropriate documentation for the alternative methods used to measure the corrosion rates of waste package materials.

The DOE response identifies that DOE has adopted three standards for conducting immersion tests: ASTM G31-72, ASTM G4-01, and ASTM G1-90. DOE takes two exceptions to ASTM G31 and one exception to ASTM G1. The NRC evaluation of the justification for these exceptions follow.

The first exception involves the ASTM G31 recommendation for documenting the original surface preparation of the test specimens, which is intended to allow an objective post-test evaluation of the test specimens. In the TBD (Bechtel SAIC Company, LLC, 2003a), DOE has indicated that no scanning electron images of the specimens were obtained prior to exposure in the long-term corrosion test facility. While pre-test scanning electron microscope images are not required by the standard, they are now considered to be a good practice. However, the post-test scanning electron microscopic images would have shown localized corrosion of the test specimens. Since the post-test images are sufficient to detect the initiation of localized corrosion in the immersion tests, the NRC finds this exception to ASTM G31 acceptable.

The second exception involves the ASTM G31 (ASTM International 1999a) recommendation for the immersion testing time. The standard provides a formula for setting a testing time to allow for the initiation of accelerated or localized corrosion processes. Because of the slow corrosion rates of Alloy 22, the formula in the standards suggests a testing time of 50 to 60 years, however, DOE's immersion tests were conducted for 5 years. Although no localized corrosion or stress corrosion cracking of Alloy 22 or titanium alloys were observed in the long-term immersion tests, separate tests were conducted to obtain parameters for the localized corrosion and stress corrosion cracking abstractions. Using electrochemical techniques, DOE was able to corroborate the results of the 5-year immersion tests by showing that the corrosion rates are slow and decrease with time. Since the results of the electrochemical tests corroborate the results of the immersion tests, the NRC finds this exception to ASTM G31 acceptable.

The third exception involves the ASTM G1 recommendation for using uncorroded test specimens with the same characteristics as those being tested to determine that the post testing cleaning procedure is not removing base metal. However, DOE did not have any uncorroded test specimens as recommended by the standard, so DOE used Alloy 22 from a different heat than the Alloy 22 specimens exposed in the long-term corrosion test facility to determine the acceptability of the post-test cleaning procedure. Since the variation in uniform corrosion rate and localized corrosion susceptibility of the Alloy 22 heats in the mill-annealed condition are similar, the NRC finds this exception to ASTM G1 acceptable.

DOE has provided appropriate documentation for the alternative methods used to measure the corrosion rates of waste package materials. DOE has also adopted appropriate standards for the immersion tests and justified three exceptions to the standards. Based upon NRC's review of the DOE response to CLST 1.07 and CLST 1.07 AIN-1, in accordance with methods discussed in the appropriate section of the YMRP, (Section 2.2.1.3.1.2, Review Method 2) NRC found DOE's response to the agreement to be satisfactory.

4.2.2 CLST 1.16

Issues related to the measurements of the thermal profile of the waste package material due to induction annealing discussed in the response to CLST 1.16 are included in the integrated subissue for degradation of engineered barriers. The agreement CLST 1.16 resulted from a staff review of DOE documentation that is consistent with Review Method 2 in Section 2.2.1.3.1.2 of the YMRP (NRC, 2003). The NRC's review of the response also was conducted in accordance with the aforementioned review method. This review method includes evaluation of the sufficiency of the experimental data used to support parameters in the conceptual models and process-level models.

The focus of agreement was to ensure that the potential metallurgical changes in the Alloy 22 closure weld resulting from the induction annealing process were appropriately characterized. The heating and rapid cooling of the extended outer closure lid weld in the induction annealing process can result in the formation of topologically close-packed phases. These secondary phases can significantly decrease localized corrosion resistance and degrade the mechanical properties of Alloy 22.

The design of the waste package has been changed, and laser peening or controlled plasticity burnishing will be used to mitigate residual stresses in the vicinity of the closure weld instead of induction annealing. These stress mitigation processes will not result in exposure of the waste package to elevated temperatures where topologically close-packed phases are thermodynamically stable. Because the revised waste package design will not use induction annealing to mitigate residual stresses in the vicinity of the outer lid closure weld, the information requested in CLST 1.16 is not necessary. Based upon NRC's review of the DOE response to CLST 1.16 in accordance with methods discussed in the appropriate section of the YMRP, (Section 2.2.1.3.1.2, Review Method 2) NRC found DOE's response to the agreement to be satisfactory.

5.0 SUMMARY

The NRC reviewed the DOE Key Technical Issue Agreement responses within the report to determine whether any important aspect of agreements CLST 1.07 and CLST 1.16 were excluded from the response. In addition, NRC performed an independent assessment to determine whether the information provided would support submission of a potential license application for a geologic repository. Notwithstanding new information that could raise new questions or comments concerning these agreements, the information provided satisfies the intent of the agreements. On the basis of this review, NRC agrees with the DOE that the information assembled in response to agreements CLST 1.07 and CLST 1.16 is adequate to support the submission of the license application for the potential repository at Yucca Mountain.

6.0 STATUS OF THE AGREEMENTS

Based on the above review, NRC staff agrees with DOE that the information provided with respect to agreements CLST 1.07 and 1.16 is adequate to support the submission of the license application. Therefore, NRC considers agreements CLST 1.07 and 1.16 to be complete.

7.0 REFERENCES

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