THE U.S. NUCLEAR REGULATORY COMMISSION OFFICE OF NUCLEAR MATERIAL SAFETY AND SAFEGUARDS REVIEW OF THE U.S. DEPARTMENT OF ENERGY KEY TECHNICAL ISSUE AGREEMENT RESPONSE TO REPOSITORY DESIGN AND THERMAL-MECHANICAL EFFECTS 3.18 FOR A POTENTIAL GEOLOGIC REPOSITORY AT YUCCA MOUNTAIN, NEVADA

1.0 INTRODUCTION

By letter dated December 9, 2003, U.S. Department of Energy (DOE) submitted the report, Technical Basis Document No. 6: Waste Package and Drip Shield Corrosion (Bechtel SAIC Company, LLC, 2003a). This technical basis document and the appendixes were provided to satisfy the informational needs of numerous key technical issue (KTI) agreement items pertaining to the environmental degradation of the waste package and drip shield materials and to respond to issues raised by the U.S. Nuclear Regulatory Commission (NRC) related to corrosion processes and the designs of the waste package and drip shield at the potential repository at Yucca Mountain, Nevada. The information was requested by NRC during previous technical exchanges in September 2000, February 2001, July 2001, August 2001, and September 2001. The specific agreement addressed in this NRC review regarding the information provided by DOE in the technical basis document is RDTME.3.18 (Reamer, 2001). RDTME.3.18 was addressed in Appendix F of Technical Basis Document No. 6.

2.0 AGREEMENT

The wording of the agreement is as follows:

RDTME.3.18

“Provide a technical basis for a stress measure that can be used as the equivalent uniaxial stress for assessing the susceptibility of the various engineered barrier system materials to stress corrosion cracking. The proposed stress measure must be consistent and compatible with the methods proposed by the DOE to assess stress corrosion cracking of the containers in WAPDEG and in accordance with the agreements reached at the Container Life and Source Term Technical Exchange. DOE will include a detailed discussion of the stress measure used to determine nucleation of stress corrosion cracks in the calculations performed to evaluate waste package barriers and the drip shield against stress corrosion cracking criterion. DOE will include these descriptions in future revisions of the following: Design Analysis for UCF Waste Packages, ANL-UDC-MD-000001, Design Analysis for the Defense High-Level Waste Disposal Container, ANL-DDC-ME-000001, Design Analysis for the Naval SNF Waste Package, ANL-UDC-ME-000001, and Design Analysis for the Ex-Container Components, ANL-XCS-ME-000001. The stresses reported in these documents will be used in WAPDEG and will be consistent with the agreements and associated schedule made at the Container Life and Source Term Technical Exchange (Subissue 1, Agreement 14, Subissue 6, Agreement 1).’’

3.0 RELEVANCE TO OVERALL PERFORMANCE

Agreement RDTME.3.18 is related to stress corrosion cracking of the proposed engineered barrier system materials. 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 lifetimes. 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. Fabrication processes, such as cold working, welding, and postweld heat treatments, may alter the corrosion resistance of the waste package materials. Mechanical loading of the waste package as a result of handling during emplacement, seismic events, rockfall, and drift degradation may result in the formation of applied or residual stresses that, in turn, can promote stress corrosion cracking.

Drip shield performance is an important factor regarding safety because the drip shields are incorporated into the design of the engineered barrier system to limit the amount of water contacting the waste package from dripping and preventing rockfall damage. Initiation of aqueous corrosion of the waste packages depends on the deliquescence of dust or the contact with seepage water. Presence of the drip shields will delay 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 the 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.

NRC performed a risk insights analysis that indicates stress corrosion cracking of the waste package closure welds has a medium significance to waste isolation (NRC, 2004). Stress corrosion cracks that penetrate through the waste package outer containers will allow water to contact the waste forms and release radionuclides, to be released the transport of water and the release rate of the radionuclides may be restricted by the small apertures of the cracks. The integrity of the drip shield also has a medium significance to waste isolation because, while intact, the drip shield will limit the quantity of water contacting the waste packages and waste forms and also limit the formation of aggressive environments on the waste package surfaces. The geometry of cracks in the waste package and the drip shield may be altered by applied loads from external events such as rockfall, seismic events, and drift degradation.

4.0 RESULTS OF THE NRC REVIEW

Agreement RDTME.3.18 is included in the integrated subissue for degradation of engineered barriers. This agreement resulted from a staff review of DOE documentation that is consistent with Review Method 2 in Section 2.2.1.3.1.2 of NRC (2003). The NRC review of the response for this agreement 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 used in conceptual models and process-level models.

Appendix F of the technical basis document indicates the current stress measure used to determine nucleation of stress corrosion cracks in calculations performed to evaluate the Alloy 22 waste package outer shell and the Titanium Grade 7 drip shield is the principal stress. Stress corrosion cracking is assumed to initiate when the applied or residual principal stress exceeds the threshold stress for stress corrosion cracking. Details of the threshold stress criterion are described in Bechtel SAIC Company, LLC (2003b). Below this threshold stress value, initiation of stress corrosion cracking will not occur on a smooth surface. The threshold stress criterion is based primarily on uniaxial test data plus results obtained on U-bend specimens in a biaxial stress state. DOE's response indicates the application of the uniaxial stress-strain information to multiaxial conditions requires the determination of principal stresses from stress analyses (Bechtel SAIC Company, LLC, 2003a, Appendix F). The following statement is included in the response to RDTME.3.18:

> "In fact, the use of all stress components to determine principal stress for comparison against allowable stresses (from a uniaxial test) may be conservative, because it appears that initiation and failure is a function of the maximum stress only in a specific direction."

This statement may not be accurate for all combinations of stresses and does not clarify DOE's definition of the stress measure for stress corrosion cracking. It is well known from solid mechanics theory that the maximum normal stress (i.e., largest algebraic normal stress) acting at any given location is defined by the first principal stress. To properly calculate the first principal stress, all of the stresses calculated in terms of the assumed coordinate system (i.e., the 3 normal and 3 shear stress components) must be considered (Gere and Timoshenko, 1984). The details were not given about how the principal stress was incorporated into DOE's fracture mechanics approach.

DOE's response acknowledges that sharp defects, such as weld flaws, can generate significant localized redistributions and reorientations of stress. The model for stress corrosion cracking contains a threshold stress intensity factor for crack propagation. If the applied stress intensity factor remains below the threshold value, crack propagation will not occur (Bechtel SAIC Company, LLC, 2003a,b). Although the model for stress corrosion crack propagation is satisfactory, DOE does not include the presence of a defect or crack in its finite-element models. DOE made the following statements are included in the response to RDTME.3.18:

> "The stress intensity factor is a direct function of the stress perpendicular to the crack plane. Thus, it is a function only of the stress perpendicular to a specific plane and similar to looking at uniaxial test data (for the same stress at the specific plane location)."

This statement may not be accurate for all combinations of stresses and flaw/crack orientations. For example, a compressive stress acting perpendicular to the major axis of a crack can cause the crack to close and prevent crack propagation. If the compressive stress is oriented parallel to the major axis of the linear flaw or crack, the stress acting at the crack tip will be tensile and oriented in a manner consistent with mode 1 crack propagation. In this orientation, the compressive stress may promote crack propagation. The details were not given about how the various defects were considered in the DOE's fracture mechanics approach.

Although DOE's response to RDTME.3.18 contains some statements that may not be applicable for all combinations of stresses and flaw orientations, the DOE model for stress corrosion cracking uses conservative parameter values for crack initiation. The threshold stress for crack initiation from a smooth surface is 90 percent of the yield strength for Alloy 22 and 50 percent of the yield strength for Titanium Grade 7. The threshold stress intensity values for crack propagation also are conservative. For example, the threshold stress intensity for stress corrosion cracking of Alloy 22 is 3 to 29 $MPa \cdot m^{1/2}$ [2.7 to 26.4 $ksi \cdot in^{1/2}$], with a mean value of 11 $MPa \cdot m^{1/2}$ [10.0 $ksi \cdot in^{1/2}$], and is based on crack tip blunting by passive corrosion (Bechtel SAIC Company, LLC, 2003b). Experimental measurements of crack propagation suggest that crack propagation rates decrease with time, and crack growth may be arrested at these stress intensities (Andresen, et al., 2004). Moreover, the initiation of stress corrosion cracking of Alloy 22 has been observed only in tests using either cyclic loading or constant straining with high applied potentials (Andresen, et al., 2004; King, et al., 2002). No stress corrosion cracking of Alloy 22 has been observed under constant deflection conditions in simulated groundwater under acidic and alkaline conditions (Fix, et al., 2004).

The fabrication and closure of the waste package will incorporate residual stress mitigation methods to eliminate residual stresses that can promote stress corrosion crack initiation. DOE indicated the titanium drip shield (ie., Titanium Grades 7 and 24) will be emplaced in a stress-mitigated condition (Bechtel SAIC Company, LLC, 2003a). Nondestructive examination will be used to inspect the waste package. The inspection criteria will limit both the size and geometry of acceptable indications. These restrictions are designed to eliminate fabrication defects that can act as initiation sites for stress corrosion cracking.

Although the staff considers this agreement closed, DOE should consider the following comment:

> The stress mitigation measures for the drip shield may be negated if the drip shield is subjected to accumulated rockfall rubble loads. In the event these loads are transmitted to the waste package because the drip shield failed by buckling, creep, or stress corrosion cracking, the waste package may incur substantial plastic deformations within the immediate region of the drip shield and waste package contact interface.

Based on the NRC review of DOE's response to Agreement RDTME.3.18 in accordance with methods discussed in the appropriate section of NRC (2003, Section 2.2.1.3.1.2, Review Method 2), NRC found DOE's response to the agreement satisfactory.

5.0 SUMMARY

NRC reviewed DOE's key technical issue (KTI) agreement responses within the report to determine whether any important aspect of Agreement RDTME.3.18 was 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 DOE that the information assembled in response to Agreement RDTME.3.18 is adequate to support the submission of the license application for the potential repository at Yucca Mountain.

6.0 STATUS OF THE AGREEMENT

Based on the preceding review, NRC agrees with DOE that the information provided with respect to Agreement RDTME.3.18 is adequate to support the submission of any license application. Therefore, NRC considers Agreement RDTME.3.18 to be closed.

7.0 REFERENCES

Andresen, P.L., P.W. Emigh, and G.M. Gordon. “Stress Corrosion Cracking Growth Rate Studies on Welded and Aged Alloy 22 in Concentrated Groundwater.” Proceedings of the CORROSION 2004 Conference. Paper No. 695. Houston, Texas: NACE International. 2004.

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Reamer, C.W. “NRC/DOE Technical Exchange and Management Meeting on Repository Design and Thermal-Mechanical Effects (February 20, 2001).” Letter (February 28) to S. Brocoum, DOE. Washington, DC: NRC. 2001.