OFFICE OF NUCLEAR MATERIAL SAFETY AND SAFEGUARDS REVIEW OF THE U.S. DEPARTMENT OF ENERGY KEY TECHNICAL ISSUE AGREEMENT RESPONSE TO CLST.2.04, 2.05 AND PRE.7.03, 7.05 FOR A POTENTIAL GEOLOGIC REPOSITORY AT YUCCA MOUNTAIN, NEVADA

1.0 INTRODUCTION

By letters dated December 9, 2003, June 24, 2004, June 30, 2004, and July 8, 2004, the U.S. Department of Energy (DOE) submitted a report, “Technical Basis Document No. 6 (TBD 6): Waste Package and Drip Shield Corrosion and Appendices Q, T, and U (Bechtel SAIC Company, LLC, 2004a,b,c; 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 U.S. Nuclear Regulatory Commission (NRC) related to corrosion processes and design 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. Specific agreements addressed in this NRC review of the information provided by DOE in the aforementioned technical basis document and appendixes include CLST.2.04, 2.05 (Schlueter, 2000) and PRE.7.03, 7.05 (Reamer, 2001).

2.0 AGREEMENTS

Wordings of the four agreements are provided next.

CLST.2.04

“Provide information on the effect of the entire fabrication sequence on phase instability of Alloy 22, including the effect of welding thick sections using multiple weld passes and the proposed induction annealing process. DOE stated that the aging studies will be expanded to include solution annealed and induction annealed Alloy 22 weld and base metal samples from the mock-ups as well as laser peened thick, multi-pass welds. This information will be included in revisions of the AMR ‘Aging and Phase Stability of the Waste Package Outer Barrier,’ ANL–EBS–MD–000002, before LA.”

CLST.2.05

“Provide the ‘Aging and Phase Stability of Waste Package Outer Barrier,’ AMR, including the documentation of the path forward items listed in the ‘Subissue 2: Effects of Phase Instability of Materials and Initial Defects on the Mechanical Failure and Lifetime of the Containers’ presentation, slides 5 & 6. [Data input to current models is being further evaluated and quantified to reduce uncertainty; aging of Alloy 22 samples for microstructural characterization, tensile property test, and Charpy impact test is ongoing; theoretical modeling will be employed to enhance confidence in extrapolating aging kinetic data to repository thermal conditions and time scale—modeling will utilize thermodynamic principles of the processes; Alloy 22 samples for SCC compact tension test are being added to aging studies; test program will be expanded to include welded and cold worked materials; effects of stress mitigation techniques such as laser peening and induction annealing on phase instability will be investigated; aging test facility will be expanded to include aging at lower temperatures.] DOE stated that the ‘Aging and

Phase Stability of the Waste Package Outer Barrier' AMR, ANL–EBS–MD–000002, Rev. 00, was issued 3/20/00. This AMR will be revised to include the results of the path forward items before LA."

PRE.7.03

"Demonstrate that the allowed microstructural and compositional variations of Alloy 22 base metal and the allowed compositional variations in the weld filler metals used in the fabrication of the waste packages do not result in unacceptable waste package mechanical properties. DOE will provide justification that the ASME code case for Alloy 22 results in acceptable waste package mechanical properties considering allowed microstructural and compositional variations of Alloy 22 base metal and the allowed compositional variations in the weld filler metals used in the fabrication of the waste packages. DOE agrees to provide the information in FY 2003 and document the information in the Waste Package Design Methodology Report."

PRE.7.05

"Provide justification that the mechanical properties of the disposal container fabrication and waste package closure welds are adequately represented considering the (1) range of welding methods used to construct the disposal containers, (2) post weld annealing and stress mitigation processes, and (3) post weld repairs. DOE agrees to provide the information in FY03 and document the information in the Waste Package Operations Fabrication Process Report."

3.0 RELEVANCE TO OVERALL PERFORMANCE

Agreements CLST.2.04 and 2.05 are related to the effects of fabrication processes on the phase stability and the mechanical properties of the proposed Alloy 22 outer container of the waste package. 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. Fabrication processes used in the production of waste packages, including cold work during machining and forming, welding and postweld treatments such as solution annealing, and stress mitigation methods may alter the microstructure and mechanical properties of the outer waste package material. Evaluation of the effects of fabrication processes on the microstructure and mechanical properties is used to assess performance of the waste packages.

Agreements PRE.7.03 and 7.05 are related to the effects of compositional variations and fabrication processes on the mechanical properties of the outer Alloy 22 waste package fabrication and closure welds. Waste package performance is an important factor regarding preclosure safety because the waste package is the main component that prevents release of radionuclides during the preclosure period in the event of a waste package drop, objects striking the waste package, waste package collisions, and fire or thermal hazards. The responses of the waste package to the loading will be dependent on the design and the mechanical properties of the components. Material degradation, as influenced by alloy microstructural and compositional variations, as well as fabrication processes, may compromise the waste package performance.

NRC risk insights analysis indicated the waste package failure mode to be of medium significance to waste isolation (NRC, 2004). Fabrication processes may alter the mechanical properties, the passive film stability, and the localized corrosion and stress corrosion cracking resistances of the Alloy 22 outer container, which could lead to early through-wall penetration or fracture of the waste package. Effects of seismic loading on engineering barriers also are considered as having a medium significance to waste isolation. Material and structural degradations as results of fabrication effects may significantly reduce the seismic threshold load needed to cause waste package mechanical damage.

4.0 RESULTS OF THE NRC REVIEW

Agreements CLST.2.04, 2.05 and PRE.7.03, 7.05 are included in the integrated subissue for degradation of engineered barriers. These agreements resulted from a staff review of the DOE documentation that is consistent with NRC (2003, Section 2.2.1.3.1.2, Review Method 2). The NRC review of the response for these agreements also was conducted in accordance with the aforementioned review method. This review method includes evaluation of the sufficiency of the experimental data use to support parameters in conceptual models and process-level models.

4.1 CLST.2.04

The focus of CLST.2.04 was the mitigation of the detrimental effects of phase instability, mainly the precipitation of topologically close-packed phases, created by forming and welding operations during fabrication of the Alloy 22 waste package outer barrier. The DOE response provided in Appendix Q of Technical Basis Document No. 6 (Bechtel SAIC Company, LLC, 2003a, 2004c) identifies that solution annealing will be used to mitigate the detrimental effects of fabrication processes by the dissolution of topologically close-packed phases. The current outer container fabrication methods include a rapid quenching of the outer container from the solution annealing temperature of 1,120 EC [2,048 EF]. The technical basis document cited the early work of Heubner, et al. (1989) as the basis for the proposed solution annealing treatment.

The dissolution of the topologically close-packed phases during solution annealing is important because the presence of these phases can affect the mechanical properties of Alloy 22. Information that confirms the ability of the proposed solution annealing treatment to dissolve topologically close-packed phases in the outer containers, particularly the weldments, however, has not been provided. Even though information on the mitigation of the detrimental effects of phase instability is inadequate, the mechanical properties of the waste package fabrication welds will meet or exceed ASME SB–575 (American Society of Mechanical Engineers, 2001) specified minimum mechanical property requirements, as indicated in Appendix U (Bechtel SAIC Company, LLC, 2004a). The approach to screening out the effects of fabrication processes by using the mechanical properties for Alloy 22 specified in ASME SB–575 (American Society of Mechanical Engineers, 2001) is acceptable if the minimum mechanical property requirements of the Alloy 22 base metal are applicable to the fabrication welds.

Although the staff considers this agreement closed, DOE should consider the following comments if ASME SB–575 (American Society of Mechanical Engineers, 2001) specified minimum mechanical properties are not met:

- DOE evaluated the effects of compositional variation and postweld heat treatment on the mechanical properties of Alloy 22 weldments using ERNiCrMo-14 weld filler metal, as documented in Appendix T of Technical Basis Document No. 6 (Bechtel SAIC Company, LLC, 2004b). In many cases, second phases, assumed to be topologically close-packed phases, were observed in the Alloy 22 weldments following solution annealing at 1,135 °C [2,075 °F], and the mechanical properties were found to be strongly dependent on the thermal stability of the weldments. The testing program indicated that postweld heat treatment at temperatures substantially above the currently proposed solution annealing temperature may be required to eliminate the topologically close-packed phases. Consideration of the effect of these high-temperature annealing treatments on corrosion and mechanical performance is needed.

- According to test results reported by Dunn, et al. (2003), solution annealing treatments may enhance precipitation of the topologically close-packed phases in Alloy 22 welds. The proposed solution annealing treatment may not adequately mitigate the phase instability resulting from fabrication of the Alloy 22 waste package outer barrier, particularly the weldments. Dissolution of topologically close-packed phases at the proposed solution annealing temperature has not been established by DOE. Consideration that the proposed solution annealing treatment is adequate to eliminate the deleterious phases is needed.

Based on the NRC review of the DOE response to Agreement CLST.2.04 in accordance with methods discussed in the appropriate section of NRC (2003, Section 2.2.1.3.1.2, Review Method 2, NRC found the DOE response to the agreement satisfactory.

4.2 CLST.2.05

The focus of CLST.2.05 was the evaluation of the long-term material performance and stability of the outer waste package material and the effects on the mechanical failure and lifetime of the outer containers using both experimental and theoretical modeling approaches. The DOE response provided in Appendix Q of Technical Basis Document No. 6 (Bechtel SAIC Company, LLC, 2003a, 2004c) indicates that precipitation of topologically close-packed phases and long-range ordering in Alloy 22 will not occur to a significant extent at expected repository temperatures. The model predictions are conservative in comparison with experimental data.

The technical basis document showed that the extrapolations for Alloy 22 welds are based on formation of 1- and 5-vol% topologically close-packed phases. Limits on the topologically close-packed phases volume fraction for satisfactory corrosion and mechanical performance, however, have not been provided. A performance-based acceptance criteria is needed to provide bounds for the maximum allowable volume fraction of topologically close-packed phases. Even though information on the maximum allowable volume fraction of topologically close-packed phases is limited, the mechanical properties of the waste package fabrication welds will meet or exceed ASME SB–575 (American Society of Mechanical Engineers, 2001) specified minimum mechanical property requirements, as indicated in Appendix U (Bechtel SAIC Company, LLC, 2004a). The approach to screening out the effects of fabrication processes by using the mechanical properties for Alloy 22 specified in ASME SB–575 (American Society of Mechanical Engineers, 2001) is satisfactory if the minimum mechanical property requirements of the Alloy 22 base metal are applicable to the fabrication welds.

Although the staff considers this agreement closed, DOE should consider the following comments if ASME SB–575 (American Society of Mechanical Engineers, 2001) specified minimum mechanical properties are not met:

- The DOE modeling of phase transformations in Alloy 22 is based on simplified alloy systems and phases. Although the model results are considered conservative by comparison with the measured data, information about validation of the thermodynamic and mobility databases used in the model would further support the conclusions.

- The amount of precipitates in the as-welded condition is reported to be 0.16 vol%, which is significantly lower than the 2.7-vol% value in CRWMS M&O (2001). Clarification is needed to explain this observed discrepancy in the amount of precipitates in the as-welded Alloy 22 and in the acceptability of the precipitate volume fraction data documented in the DOE reports.

- Aging and phase stability experiments, as well as thermodynamic and kinetic modeling, have been or are being conducted to evaluate long-term material stability and its effect on the mechanical properties of both Alloy 22 base metal and weldments. The purpose of the ongoing work and how the results of these additional studies will be used to evaluate the effects of phase instability should be adequately addressed.

Based on the NRC review of the DOE response to Agreement CLST.2.05 in accordance with methods discussed in the appropriate section of NRC (2003, Section 2.2.1.3.1.2, Review Method 2, NRC found the DOE response to the agreement satisfactory.

4.3 PRE.7.03

The focus of PRE.7.03 was ensuring the allowed compositional variations of Alloy 22 and weld filler metal, as well as the allowed microstructural variations of Alloy 22, do not result in unacceptable waste package mechanical properties. The DOE response provided in Appendix T of Technical Basis Document No. 6 (Bechtel SAIC Company, LLC, 2003a, 2004b) provides results from a testing program that includes the compositional variations within the specifications of ASME SB–575 (American Society of Mechanical Engineers, 2001). Results of this testing program indicated that, although the mechanical properties of Alloy 22 weldments are influenced by base metal composition, filler metal composition, and heat treatment, materials procured with composition ranges of typical commercial products would provide acceptable mechanical properties.

The effect of compositional variations on thermal stability and mechanical properties for Alloy 22 base metal and welds is a concern. The basis for acceptable mechanical properties, however, has not been provided. Although specific combinations of base and filler metal compositions have significantly lower ductility and impact strengths compared with typical welds, revised compositional specifications for the alloying elements (other than iron) and trace elements are not considered necessary based on typical manufacturing practice. A performance-based acceptance criteria would provide bounds for the acceptable mechanical performance rather than typical performance. The approach to screening out the effects of fabrication processes by using the mechanical properties for Alloy 22 specified in ASME SB–575 (American Society of Mechanical Engineers, 2001) is satisfactory if the minimum mechanical property requirements of the Alloy 22 base metal are applicable to the fabrication welds.

Although the staff considers this agreement closed, DOE should consider the following comments if ASME SB–575 (American Society of Mechanical Engineers, 2001) specified minimum mechanical properties are not met:

- Internal mill specifications and commercial practices result in the production of Alloy 22 composition ranges tighter than those in ASME SB–575 (American Society of Mechanical Engineers, 2001). Information about the implementation of a material procurement program that ensures the compositional variations are bounded by the composition ranges of typical commercial products should be provided.

- The cooling rates are not provided for heat treated weldments compared with the required cooling rates for the Alloy 22 waste package outer containers. The time of exposure at temperatures where topologically close-packed phases can be formed will depend in part on the cooling rates during quenching from the solution annealing temperature. Small test specimens can be quenched quickly, and the cooling rates for the laboratory test specimens may be much greater than the specified minimum cooling rate. Therefore, it is possible that the test specimens may not be representative of the actual as-fabricated waste packages. Information on the cooling rates for the test specimens or how these rates are compared with the proposed fabrication specifications should be provided to support the conclusions.

- The precipitate volume fraction data for Alloy 22 welded samples using ERNiCrMo-10 weld filler metal have been included in Bechtel SAIC Company, LLC (2003b). Actual data for the volume fraction of topologically close-packed phases in the welds using ERNiCrMo-14 weld filler metal are useful for assessing the detrimental effects of phase instability.

Based on the NRC review of the DOE response to Agreement PRE.7.03 in accordance with methods discussed in the appropriate section of NRC (2003, Section 2.2.1.3.1.2, Review Method 2), NRC found the DOE response to the agreement satisfactory.

4.4 PRE.7.05

The focus of PRE.7.05 was the evaluation of material conditions that may affect mechanical properties and long-term performance of Alloy 22 welds. The DOE response provided in Appendix U of Technical Basis Document No. 6 (Bechtel SAIC Company, LLC, 2003a, 2004a) provides mechanical property results and indicated the mechanical properties of the waste package fabrication and closure welds will meet or exceed relevant ASME SB–575 (American Society of Mechanical Engineers, 2001) specified minimum mechanical property requirements. These waste package specifications control the range of welding processes allowed, as well as the implementation of controlled postweld heat treatment, stress mitigation processes, and postweld repairs.

The technical basis document did not provide information about how results of the tests or distribution of the mechanical properties actually will be used in models to evaluate the mechanical performance of waste packages as a result of drops or impacts. It is argued that the minimum values of the mechanical properties specified in ASME SB–575 (American Society of Mechanical Engineers, 2001) for the as-fabricated waste packages will be used. The approach of using the mechanical properties for Alloy 22 specified in ASME SB–575 (American Society of Mechanical Engineers, 2001) is satisfactory if the minimum mechanical property requirements of the Alloy 22 base metal are applicable to the fabrication welds.

Although the staff considers this agreement closed, DOE should consider the following comments if ASME SB–575 (American Society of Mechanical Engineers, 2001) specified minimum mechanical properties are not met:

- Postweld heat treatment is an issue for some base metal and filler metal compositions, as discussed in the review for CLST.2.04. Information about the acceptability of postweld mechanical properties considering the base metal and filler metal compositions should be provided.

- Although the effect of stress mitigation-related cold work on the weld mechanical properties is expected to be minimal, no mechanical property data were provided for laser peened or controlled plasticity burnished materials. Justification is needed to support that the mechanical properties of laser peened or burnished materials are acceptable.

Based on the NRC review of the DOE response to Agreement PRE.7.05 in accordance with methods discussed in the appropriate section of NRC (2003, Section 2.2.1.3.1.2, Review Method 2), NRC found the DOE response to the agreement satisfactory.

5.0 SUMMARY

NRC reviewed the DOE key technical issue agreement responses within TBD 6 and Appendices Q, T, and U to determine whether any important aspect of agreements CLST.2.04, 2.05 and PRE.7.03, 7.05 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 agreements CLST.2.04, 2.05 and PRE.7.03, 7.05 is adequate to support the submission of a license application for the potential repository at Yucca Mountain.

6.0 STATUS OF THE AGREEMENTS

Based on the preceding review, NRC agrees with DOE that the information provided with respect to agreements CLST.2.04, 2.05 and PRE.7.03, 7.05 is adequate to support submission of the license application. Therefore, NRC considers agreements CLST.2.04, 2.05 and PRE 7.03, 7.05 to be closed.

7.0 REFERENCES

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