Presentation of the Final Report of Waste Package Materials Performance Peer Review Panel

Presented by

Peer Panel on Waste Package Materials Performance

Chairman, Joe H. Payer

Presented to

U.S. Department of Energy (DOE)

Bechtel SAIC Company, LLC (BSC)

March 18-19, 2002

Las Vegas, NV

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Peer Review of Waste Package Materials Performance

The U.S. Department of Energy (DOE) requested that Bechtel SAIC Company, LLC (BSC) conduct a consensus peer review of the waste package materials performance.

Topic: Prediction of the long-term performance of waste package materials for a repository at Yucca Mountain, Nevada.

- Review the current technical basis for prediction
- Assess the planned experimental and modeling program
- Focus on corrosion performance of Alloy 22 waste package and Ti Gr 7 drip shield materials

Panel submitted Final Report to BSC/DOE on February 28, 2002

- Report is posted on ymp.gov website

Acknowledgements

- U.S. Department of Energy
- Bechtel SAIC
- Lawrence Livermore National Laboratory
- Subject Matter Experts
- U.S. Nuclear Regulatory Commission
- Center for Nuclear Waste Regulatory Analyses
- U.S. Nuclear Waste Technical Review Board
- State of Nevada Agency for Nuclear Projects and its contractors

The Panel had cooperative and open discussions with all throughout the conduct of this review.

Peer Review Panel Members

Dr. Joe H. Payer, Case Western Reserve University; Chairperson
Dr. John A. Beavers, CC Technologies Laboratories, Inc.
Dr. Thomas M. Devine, Jr., University of California, Berkeley
Dr. Gerald S. Frankel, Ohio State University
Dr. Russell H. Jones, Battelle-Northwest
Dr. Robert G. Kelly, University of Virginia
Dr. Ronald M. Latanision, Massachusetts Institute of Technology

Panel member expertise in the materials science and engineering, corrosion, and prediction of materials performance

Subject Matter Experts:

- *~15 U.S. & International to assist the Panel*
- *Expertise includes passivity, localized corrosion, geochemistry, hydrogeology, physical metallurgy, welding, oxidation*

Noteworthy Technical Exchanges

Waste Package Materials Performance Peer Review Kickoff Meeting, Las Vegas, Nevada, May 23, 2001

International Workshop on Long-Term Extrapolation of Passive Behavior, conducted by the U.S. Nuclear Waste Technical Review Board, Arlington, Virginia, July 19-20, 2001

Panel Sub-Group Meeting on Localized Corrosion, conducted by the Panel, Arlington, Virginia, July 21, 2001

State of Nevada and Nuclear Regulatory Commission Presentations to the Panel, conducted by the Panel, Cleveland, Ohio, July 24, 2001

Panel Sub-Group on Waste Package Fabrication, conducted by the Panel, Livermore, California, August 10, 2001

Panel Sub-Group Meeting on Stress Corrosion Cracking Defensive Strategies, arranged by BCS with relevant Project staff, Las Vegas, Nevada, November 12, 2001

Content of the Final Report

Executive Summary

Introduction

Overview Sections

- Section 2 provides the Panel's overall findings, presents technical issues that need to be resolved
- Section 3 presents a summary of the Panel's review and findings for specific degradation modes and factors

Detailed Sections

- Section 4 through Section 10 provide information to support the findings and recommendations

Contributing Factors

- Section 11 presents summaries drawn from Special Topic Reports (those reports to be issued in March 2002)

A Separate "Compilation of Special Topic Reports"

- To be released in March 2002.

Perspective on Proposed Yucca Mountain Repository

A geologic repository for the disposal of high-level radioactive waste and spent nuclear fuel

Containment strategy for the disposal site is twofold

- First and foremost, complete isolation of the waste
- Subsequent retardation of the egress of radionuclides from the penetrated waste package

Waste packages will be exposed to air with high relative humidity; also a possibility that water droplets will fall onto the waste packages where water seeps into the emplacement drifts

Corrosion is the most significant potential degradation mode for waste package materials, although other potential degradation modes must also be considered.

Perspective on Long-Term Materials Performance

Nickel-base Alloy 22 and Titanium Grade 7

- Principal alloys of interest for waste package and drip shield
- Excellent corrosion resistance over a wide range of aqueous solution compositions and temperatures

Two major considerations

- Fabrication processes, particularly welding, can have a major impact on corrosion resistance and performance
- Temperature has major effects on the composition of the environment and the behavior of materials.

The Panel reviewed the technical basis for long-term performance of waste package materials.

The Panel assessed the level of confidence in the Project findings, identified deficiencies, and made recommendations to strengthen the technical basis, increase confidence and reduce uncertainties.

Overall Findings

The Panel concludes, based on the body of technical information currently available, that Alloy 22 is a suitable material of construction for the outer barrier of a waste package: nevertheless, significant technical issues remain unsettled.

Technical basis supporting the suitability of Alloy 22 is substantial and growing

Always uncertainty in the evaluation of the long-term performance of materials in the repository.

- Primarily because of the extremely long life required

Confidence regarding the long-term performance of Alloy 22 can be substantially increased

- Through further experiments and analyses
- Panel recommends that this work be undertaken

Overall Findings

The Panel concludes that titanium Grade 7 might not be a suitable material of construction for the drip shield.

Stress corrosion cracking of titanium Grade 7 has been observed in laboratory tests

- If these tests are deemed to have occurred under realistic conditions
- Then the benefits of titanium are severely diminished

Panel does not recommend the use of titanium for drip shields, if it is found to be susceptible to stress corrosion cracking under realistic repository conditions

Overall Findings

The Panel has identified technical issues that have the potential to require a change in the waste package material or design and suggests approaches to the resolution of these issues.

The Panel concludes that further comprehensive analysis and testing can resolve these technical issues.

The issues are presented in Section 2.7 of the Final Report and will be discussed at this meeting.

Overall Findings

Control of corrosion of waste package materials is essential to satisfactory long-term performance.

- The Panel concludes that the Project staff is taking a sound approach to analyzing corrosion related issues

Although the nominal waters at Yucca Mountain are fairly benign and not corrosive, water composition can change at the metal surface.

- The Panel recommends the formation of a task group of Project technical experts to determine the range of environments that could be in contact with hot metal surfaces.

Corrosion and mechanical behavior of waste packages must be considered in the selection of design and fabrication methods.

- The Panel concludes that it is time to balance the materials/corrosion work to support performance assessment with work to support design and fabrication of the waste packages.

Corrosion Degradation Modes

Uniform Corrosion

- Failure of the waste package during the design life by uniform corrosion is unlikely
- It is highly likely that the passive film will remain stable and uniform corrosion rates will remain very low
- Two phenomena that could jeopardize the desirable long-term behavior are worthy of study: (a) surface segregation of sulfur and (b) transpassive corrosion.

The Panel concludes that there is a substantial and growing technical basis to support the evaluation of the long-term performance of waste package materials in this area.

Corrosion Degradation Modes

Localized Corrosion

- Nickel-base Alloy 22 and titanium Grade 7 are extremely resistant to localized corrosion
- Nevertheless, these alloys are susceptible to crevice corrosion under extreme conditions of environment and potential
- The Panel recommends that the Project perform experiments under conditions beyond those thought to be relevant to Yucca Mountain in order to examine the margins of corrosion resistance.
  - The framework used by the Project for the evaluation of resistance to crevice corrosion is appropriate
  - The Panel recommends a more rigorous approach for determination of the critical potentials

The Panel concludes that there is a substantial and growing technical basis to support the evaluation of the long-term performance of waste package materials in this area.

Corrosion Degradation Modes

Stress Corrosion Cracking

Nickel base Alloy 22 is highly resistant to stress corrosion cracking in the environments expected in the repository

- The mitigation method, experimental approach, and modeling efforts for stress corrosion cracking are consistent with the state-of-the-art
- Appropriate work generally is underway to verify the models
- The Panel recommends additional work to address some deficiencies in the current program

The Panel concludes that there is a substantial and growing technical basis to support the evaluation of the long-term performance of waste package materials in this area.

Corrosion Degradation Modes

Stress Corrosion Cracking

- The Panel recommends that the Project consider alternative models for stress corrosion cracking and additional research to address issues associated with verification of the models.
- The Panel recommends that the effectiveness of heat treatment for stress mitigation be thoroughly evaluated.
- The Panel further recommends that the stress corrosion cracking behavior of Alloy 22 be evaluated with different stages of aging and in environments containing trace impurities, such as lead.

Higher or Lower Temperature Operating Modes

Considerable interest in the effect of operating temperature on the long-term performance of the repository

- High temperature mode: waste package surface no more than 180° C
- Low temperature mode: waste package surface no more than 85°C

Incentives for lower temperatures operation

- reduced corrosion rates,
- lower likelihood of localized corrosion or detrimental metallurgical aging processes
- less opportunity for evaporative condensation.

Disincentives of lower temperature operation

- Expose wet waste package surfaces to higher radiation fields and radiolysis
- Increased costs and risks associated with longer ventilation periods
- A larger repository area required for a given amount of spent fuel

As with most design/operation decisions, there are tradeoffs associated with lowering the temperature

Alloy Specification and Comparison

The Panel regards Alloy 22 as a representative member of a family of highly corrosion resistant nickel-chromium-molybdenum alloys

- Today's commercial alloys arose from a steady evolution in alloy development.
- Unlikely that the evolution is complete

The Panel recommends that the Project staff determine the effects of alloy composition within the specified ranges of Alloy 22

- Chemical composition of heats of commercially available Alloy 22 can vary within the specified range for each element
- A more restrictive chemical composition specification might increase confidence with respect to long-term performance

The Panel recommends that the Project not designate metals less corrosion resistant than Alloy 22 type metals

The Panel recommends inclusion of a back-up alloy and a group of comparative alloys in certain of the tests performed

Technical Issues to be Resolved

Current waste package design is likely to meet the desired performance criteria, if these issues are resolved favorably

- Potential to require a change in the waste package material or design
- Further comprehensive analysis and testing can resolve the issues

Need to strengthen the technical basis for assessing waste package performance is clearly recognized by the Project staff

- Extensive experimental and analytical work has been completed
- Large amount of necessary work remains in Project plans

The Panel is concerned that adequate resources might not be allocated to complete the work necessary for evaluating the long-term performance of waste package materials

- Substantial effort is required to accomplish the needed work to support design and fabrication of durable waste packages
- Panel strongly recommends adequate resources be provided

This area is particularly amenable to progress through experiments and modeling to substantially build confidence in the long-term performance of waste packages.

Technical Issues to be Resolved

- Design and fabrication procedures
- Development and validation of weld procedures
- Realistic boundaries for environmental conditions
- Corrosion behavior within the range of realistic environmental conditions
- Radiolysis from gamma radiation at realistic levels
- Proper measure of crevice corrosion susceptibility
- Corrosion potential over long periods
- Long-term metallurgical stability: Cr-Mo depletion and Long Range Ordering
- Effects of sulfur and phosphorus
- Effectiveness of tensile stress reduction for mitigating stress corrosion cracking
- Stress corrosion crack growth and consequence
- Hydrogen embrittlement of Alloy 22

Organizational-Managerial Issues

Two areas were identified that require further focus and integration of Project efforts.

Determination of the realistic range of aqueous environments on waste package surfaces

- The Panel recommends the direct, collaborative participation of the Project's technical experts in corrosion, materials science, geochemistry, and hydrology in work on these conditions

Design and fabrication of waste packages for corrosion resistance

- The Panel recommends closer integration between the design and fabrication engineers and the corrosion and materials experts working on performance assessment.

Organizational-Managerial Issues

Current management and administrative policies and procedures tend to limit broader involvement of technical experts from academia and industry

- Conceptual work, experimental method development, and analytical procedures
- Need more effective means to engage a broader base of the corrosion science and engineering community
- Work relevant to the long-term performance of materials at Yucca Mountain would have significant benefits

Organizational-Managerial Issues

The Panel recommends the establishment of an External Advisory Board.

- Helpful in determining and maintaining focus and direction in the execution of the research agenda
- Include both academics and industrial experts with credentials in areas important to the Project

There is no visible senior, visionary leader with a deep materials science and engineering background and management credentials

Waste package design is likely to meet the performance criteria for the repository, if some technical issues are favorably resolved.

Corrosion and mechanical behavior of waste packages must be considered in the selection of design and fabrication methods.

The Panel concludes that it is time to balance the materials/corrosion work to support performance assessment with work to support design and fabrication of the waste packages