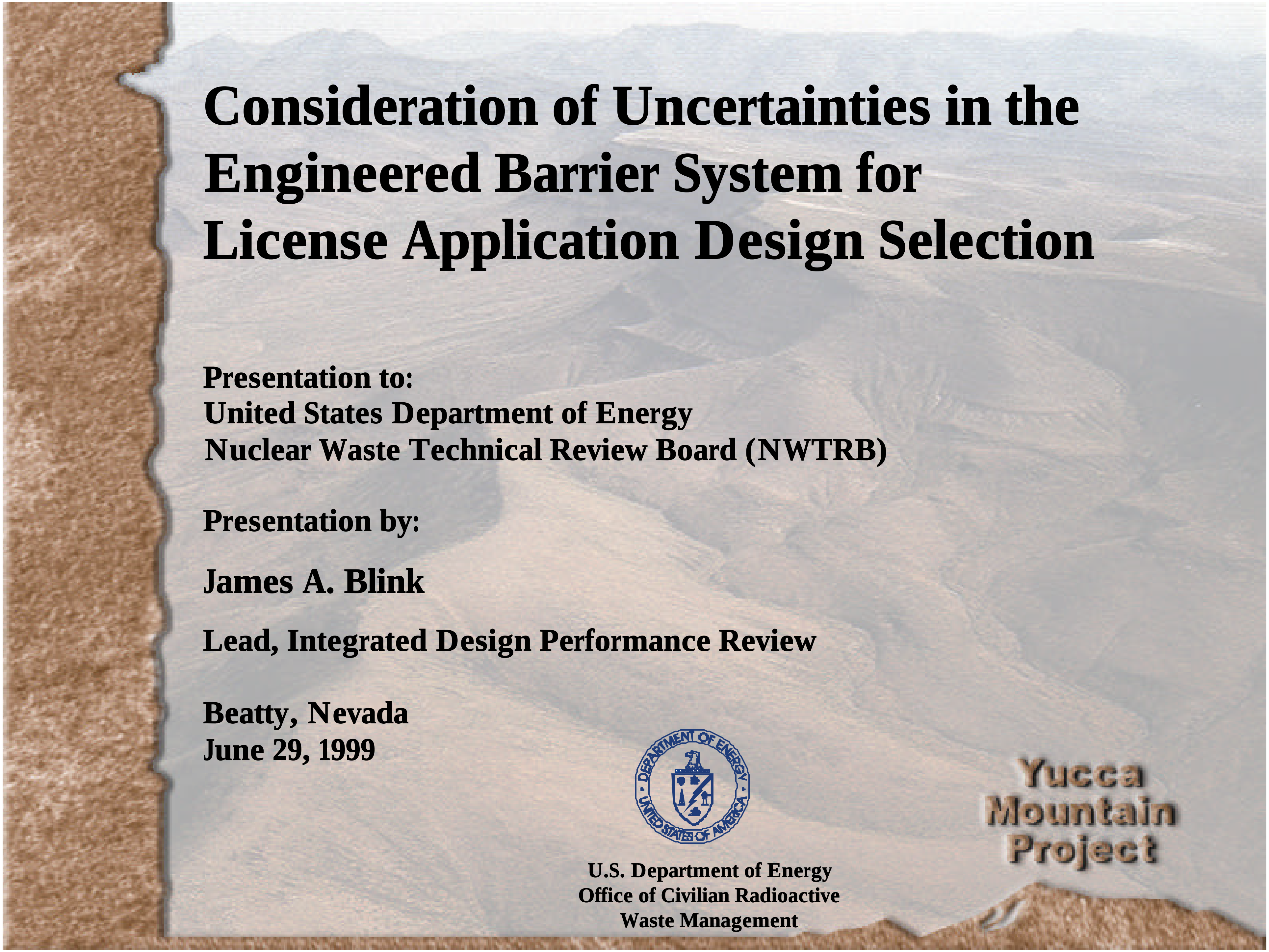


Consideration of Uncertainties in the Engineered Barrier System for License Application Design Selection

Presentation to:
United States Department of Energy
Nuclear Waste Technical Review Board (NWTRB)

Presentation by:

James A. Blink

Lead, Integrated Design Performance Review

Beatty, Nevada
June 29, 1999

U.S. Department of Energy
Office of Civilian Radioactive
Waste Management

Yucca
Mountain
Project

Scope of the Presentation

- **Uncertainties in corrosion of engineered materials used in the waste package and drip shield**
  - **Carbon Steel**
  - **Stainless Steel (316 Nuclear Grade)**
  - **Alloy 22**
  - **Titanium**
- **Changes in water chemistry at the engineered material surface**
- **Other uncertainties in the EBS (temperatures, water flow paths, backfill alteration, etc.) are discussed in the following presentation**
- **The status of testing and modeling of corrosion uncertainties will be presented tomorrow**

Carbon Steel in EDAs - 1

Use in VA

- **The VA design uses carbon steel as the outer waste package barrier**
  - **Structural strength**
  - **Rugged handling surface**
  - **Sacrificial corrosion allowance material (CAM)**
    - » **Delays initiation of corrosion of the corrosion resistance material (CRM) during the thermal pulse**

Carbon Steel in EDAs - 2

Oxide Wedging

- EDAs I, II, III, and V did not use carbon steel, to avoid potential oxide wedging of the CRM
  - General corrosion is more rapid than in CRMs due to spalling of the expanded oxides
  - In a confined geometry, general corrosion of carbon steel can potentially cause stresses high enough to rupture or buckle adjacent materials (oxide wedging)
- The ground support, waste package support, and invert can be designed to avoid oxide wedging or hydrogen embrittlement of the CRMs by carbon steel

Carbon Steel in EDAs - 3

Use in EDA IV

- **EDA IV uses a thick carbon steel waste package to permit human access to drifts to respond to off-normal events**
  - **Backfill elevates temperatures and depresses humidity; general corrosion does not breach the WP within 10,000 yrs**
  - **Beyond 10,000 years, the EDA IV WPs breach sooner than the EDAs using Alloy 22**
- **Pitting of carbon steel is also modeled**
  - **Likely in alkaline environments (in the presence of concrete)**
  - **Probably would cease growing prior to penetrating a thick shell**

Stainless Steel in EDAs - 1

Structural and General Corrosion Considerations

- **EDAs I, II, III, and V use a 5-cm-thick structural shell protected by the CRM**
- **Stainless steel corrosion cannot begin until the outer CRM is breached**
  - **Structural lifetime is >10^5 yr for EDAs I, II, III, and V**
  - **Structural lifetime is <10^4 yr for VA**
- **General Corrosion**
  - **Very slow. If this is the dominant failure mode, the structural shell will provide significant corrosion lifetime (>1000 yrs)**
  - **Oxide wedging is not an issue**

Stainless Steel in EDAs - 2

Pitting, Stress Corrosion Cracking, Lifetime

- **Pitting**
  - **Aggressive in un-buffered environments. May be negligible in ambient temperature environment that contains buffers**
- **Stress Corrosion Cracking**
  - **Not an issue until water contacts the steel**
  - **Uncertainty and variability in mechanical contact stresses for multi-shell WPs requires further investigation**
- **Overall**
  - **Low temperature, low thermal stress, and buffered environment conditions at the time of CRM breach may result in significant stainless steel lifetime**
  - **Due to uncertainties, no lifetime was used in the PA calculations for the EDAs**

Alloy 22 in EDAs - 1

Corrosion Resistant Material in WPs

- **EDAs I, II, III, and V:**
  - **Use Alloy 22 as the outer shell to avoid crevice corrosion geometries**
  - **Limit temperatures, using preclosure ventilation and (for EDAs I, II, and V) blending**
  - **Limit seepage water contact, particularly when temperatures are high, by using a drip shield**
- **EDAs I and II:**
  - **Return to low temperatures well before the drip shield corrodes**
- **EDA II:**
  - **Uses backfill to thermally limit relative humidity (and aqueous corrosion modes) while temperatures are above 85ºC**

Alloy 22 in EDAs - 2

General Corrosion and Pitting

- **General corrosion**
  - **Extremely slow**
  - **If this is the dominant mode, a 2 cm thick layer could last for hundreds of thousands of years**
- **Pits probably will not initiate at temperatures below the boiling point of water at the repository elevation**

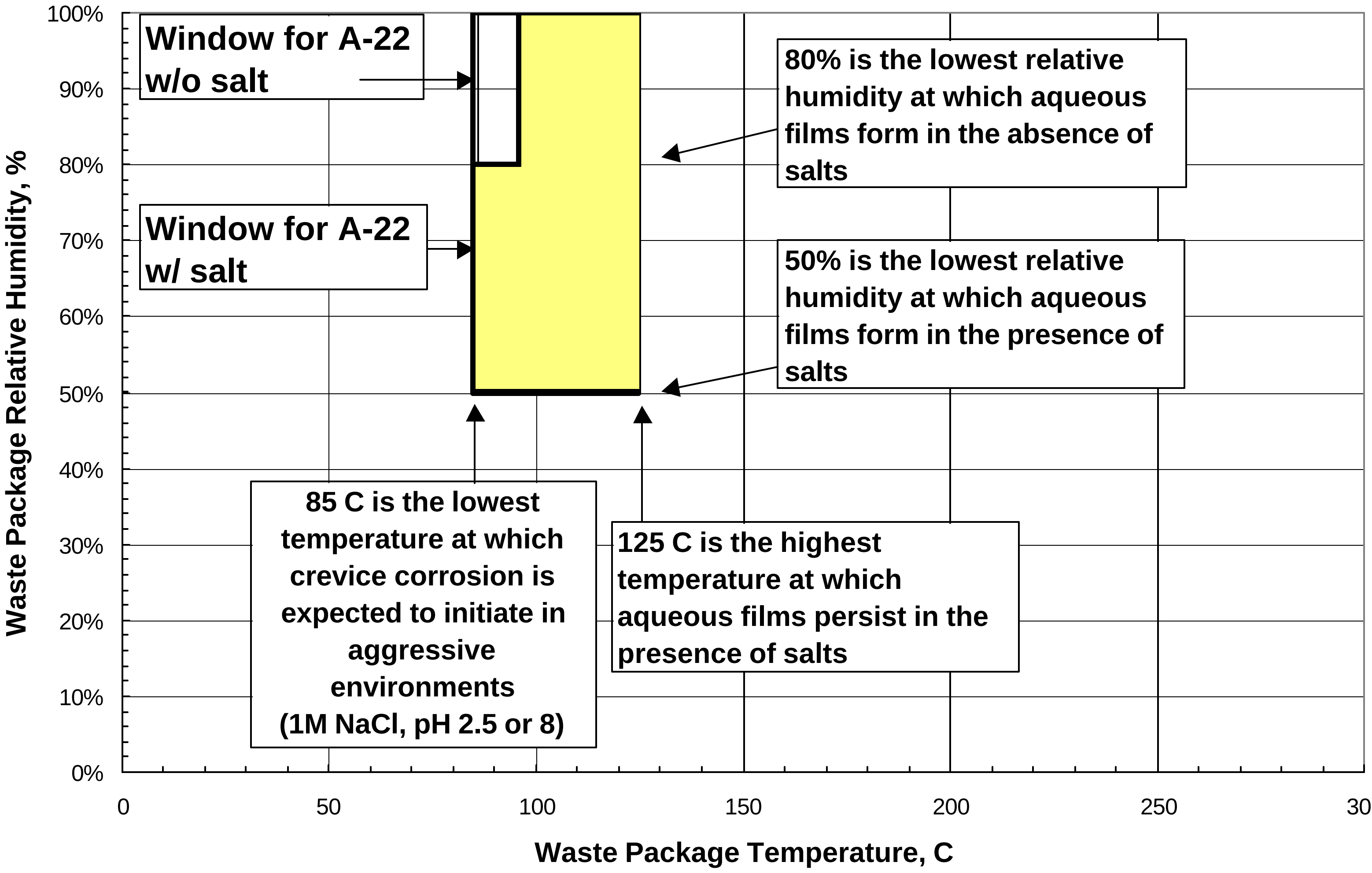
Alloy 22 in EDAs - 3

Crevice Corrosion

- **For clean metal and no dripping water**
  - **Crevice corrosion will probably not initiate at temperatures below the boiling point of water at the repository elevation**
- **For limited salts in aqueous films**
  - **Crevice corrosion may initiate at temperatures above 85ºC**
    - **For limited quantities of sodium chloride salts**
    - **More aggressive cations, Ca and Mg, precipitate out of the film**
- **For dripping concentrated (2000x) seepage water**
  - **Crevice corrosion may initiate at temperatures above 85ºC and down to 50% relative humidity**
- **Crevice geometries**
  - **Avoided by WP designs with Alloy 22 as the outer shell**
  - **Attention should be paid to the interface with WP supports and the invert ballast following support degradation**

Alloy 22 in EDAs - 4

Crevice Corrosion Window of Susceptibility



Window for A-22 w/o salt

Window for A-22 w/ salt

80% is the lowest relative humidity at which aqueous films form in the absence of salts

50% is the lowest relative humidity at which aqueous films form in the presence of salts

85 C is the lowest temperature at which crevice corrosion is expected to initiate in aggressive environments (1M NaCl, pH 2.5 or 8)

125 C is the highest temperature at which aqueous films persist in the presence of salts

Alloy 22 in EDAs - 5

Stress Corrosion Cracking and Hydrogen Embrittlement

- **SCC is more likely at high stress, high temperature, and with aggressive species in the water**
  - **Hydrogen embrittlement can also cause cracking**
- **The likelihood of and extent of SCC is reduced by**
  - **Excluding seepage water or consuming halides while temperatures are high**
  - **Stress relief of WP welds (thermally or mechanically)**
- **The likelihood of hydrogen embrittlement is reduced by separation of Alloy 22 from carbon steel**

Alloy 22 in EDAs - 6

Microbial Influenced Corrosion

- **Microbial activity can produce acidic local conditions which increase some modes of corrosion**
- **Microbes are dormant at temperatures above boiling**
- **Some microbial activity is nutrient-limited in repository environments**

Alloy 22 in EDAs - 7

Phase Transformation

- At extended high temperatures, the phase structure evolves
  - Concentrating some alloying elements in new phases
  - Depleting them in adjacent regions
- Corrosion may proceed through regions depleted in alloying elements
  - If they form the protective oxides that resist dissolution in a particular pH environment
- Preliminary testing and modeling indicate that phase stability may not be an issue at temperatures below 350ºC for the base metal
  - Weld material has some of the new phases. Further study of welds is required

Alloy 22 in EDAs - 8

Long Range Ordering

- At extended medium temperatures, the crystalline structure within grains develops a long range order
  - Can increase susceptibility to stress corrosion cracking
- Testing is evaluating the extent and consequences of ordering at repository temperatures

Titanium Grade 7 in EDAs - 1

Corrosion Resistant Material in Drip Shields

- **All 5 EDAs use Ti-Gr7 as a drip shield material**
- **Use of different corrosion resistant materials in the drip shield and waste package adds diversity and defense in depth**
- **PA conservatively assumed that the first drip shield failure occurs above the single assumed juvenile failed WP**
- **The drip shield lifetime must be long enough to prevent seepage from contacting the waste package while temperature is high**
- **Corrosion at the interface of backfill or rockfall with the drip shield requires further evaluation**

Titanium Grade 7 in EDAs - 2

General, Pitting, and Crevice Corrosion

- **General corrosion**
  - **Extremely slow**
  - **If this is the dominant mode, a 2 cm thick layer could last for tens of thousand years**
- **Pitting**
  - **High fluoride levels can accelerate pitting**
- **Backfill or rockfall contact with the drip shield can result in crevice geometries**
- **Testing has not produced pitting in Ti alloys exposed to repository environments, including fluoride**

Titanium Grade 7 in EDAs - 3

Hydrogen Embrittlement

- **Aqueous corrosion of iron in contact with titanium can provide a source of hydrogen that can diffuse into the titanium, embrittling it**
- **Grade 7 may be less susceptible to this mode than other titanium alloys**
- **Backfill physically separates the Ti drip shield from degraded, but not fully corroded, iron ground support components**
  - **Invert materials can be chosen to avoid hydrogen embrittlement of a Ti drip shield that rests on the invert**

Titanium Grade 7 in EDAs - 4

Stress Corrosion Cracking, Microbial Influenced Corrosion

- **SCC is more likely at high stress, high temperature, and with aggressive species in the water**
  - **Stress relief of Ti welds (thermally or mechanically) reduces the possibility of SCC**
- **Ti alloys are highly resistant to MIC**

Modifications to Surface Chemistry

- Reactions at the corroding surfaces of engineered components have the potential to increase corrosion rates
  - MIC is caused by microbial activity reducing pH
  - Crevice corrosion in a carbon steel-to-Alloy 22 interface can be accelerated by ferric chloride formation in a crevice.
  - Aqueous corrosion of iron (carbon or stainless steels) in contact with titanium or Alloy 22 may provide a source of hydrogen which can embrittle the CRMs
  - Evaporative deposition of salts on drip shield and WP surfaces can be protective or form crevices which are detrimental

Surface Chemistry in EDAs

- **The EDAs seek to minimize deleterious surface chemistry modifications**
  - **Ti-Gr7 and Alloy 22 are very resistant to acidic environments, such as those caused by microbial activity**
  - **Drip shields minimize evaporative deposition of salts on WP surfaces during the thermal pulse. The backfill in EDAs II and IV further reduce salt deposition**
  - **All EDAs avoid carbon steel-to-Alloy 22 crevices**
  - **Detailed design can physically separate steel support components from the CRMs. The backfill in EDAs II and IV contributes to the separation**

EBS Uncertainties, Summary

- The EDAs consider known degradation modes of engineered materials, and use thermal, geometric, and material interface design choices to avoid or mitigate the modes
- Confidence in EBS performance is enhanced by
  - Defense in depth: Using multiple materials with different mechanistic behaviors
  - Testing and modeling; at atomic, grain, and macroscopic scales; to develop mechanistic understanding of material behavior
  - Performance confirmation testing