Role of Engineered Barrier System in Deep Borehole Disposal

Characteristics and Issues

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Main Questions

- How much reliance should be placed on EBS?
- What characteristics of EBS are important ?
- What is our knowledge regarding EBS characteristics?

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How much reliance should be placed on the EBS?

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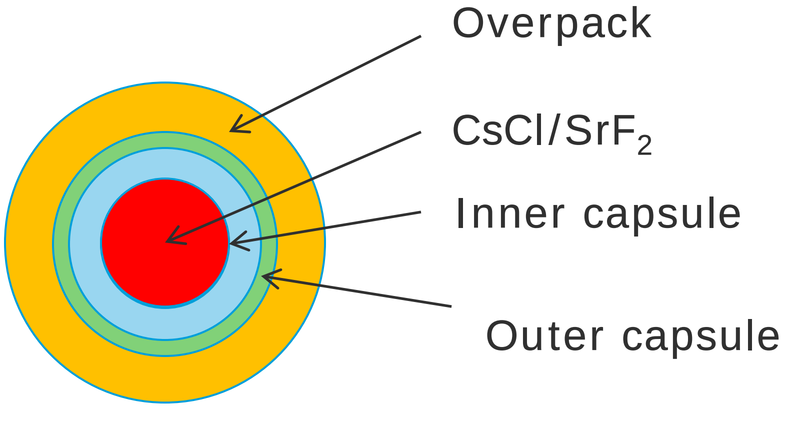
EBS

- EBS consists of borehole seals, backfills, containers, and waste forms
  - Focus of this presentation: overpack and capsules
- Potential role of overpack in DB concept
  - Overcome uncertainties related to drilling and completion operations
  - Uncertainties related to packers, plug performance
  - Uncertainties related to casing performance
  - Degradation of capsules



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Degradation of down hole materials

- Down hole environment
  - Chloride, fluoride, other anionic species
  - CO_2, H_2S, S^0
  - Hg, other detrimental cationic species
  - Temperature
  - Pressure
  - Flow rate
  - Dissolved oxygen (from leaks)
- Added chemicals during drilling and completion
- Experience from geothermal programs will be key inputs

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Uncertainties in the long-term performance of packers & seals

- Degradation of packers (if they are used)
  – Potential stress corrosion cracking of packers in brine
  – Potential localized corrosion of packers
- Degradation of seals
  – Uncertainties related to shrinkage of clay
  – Effect of brine and any leakage of waste
- Degradation of interface between seal and casing
  – crevice corrosion of casing can cause hydrolysis and local acidification
  – Galvanic effects
  – Debonding of plug and creation of leakage pathway

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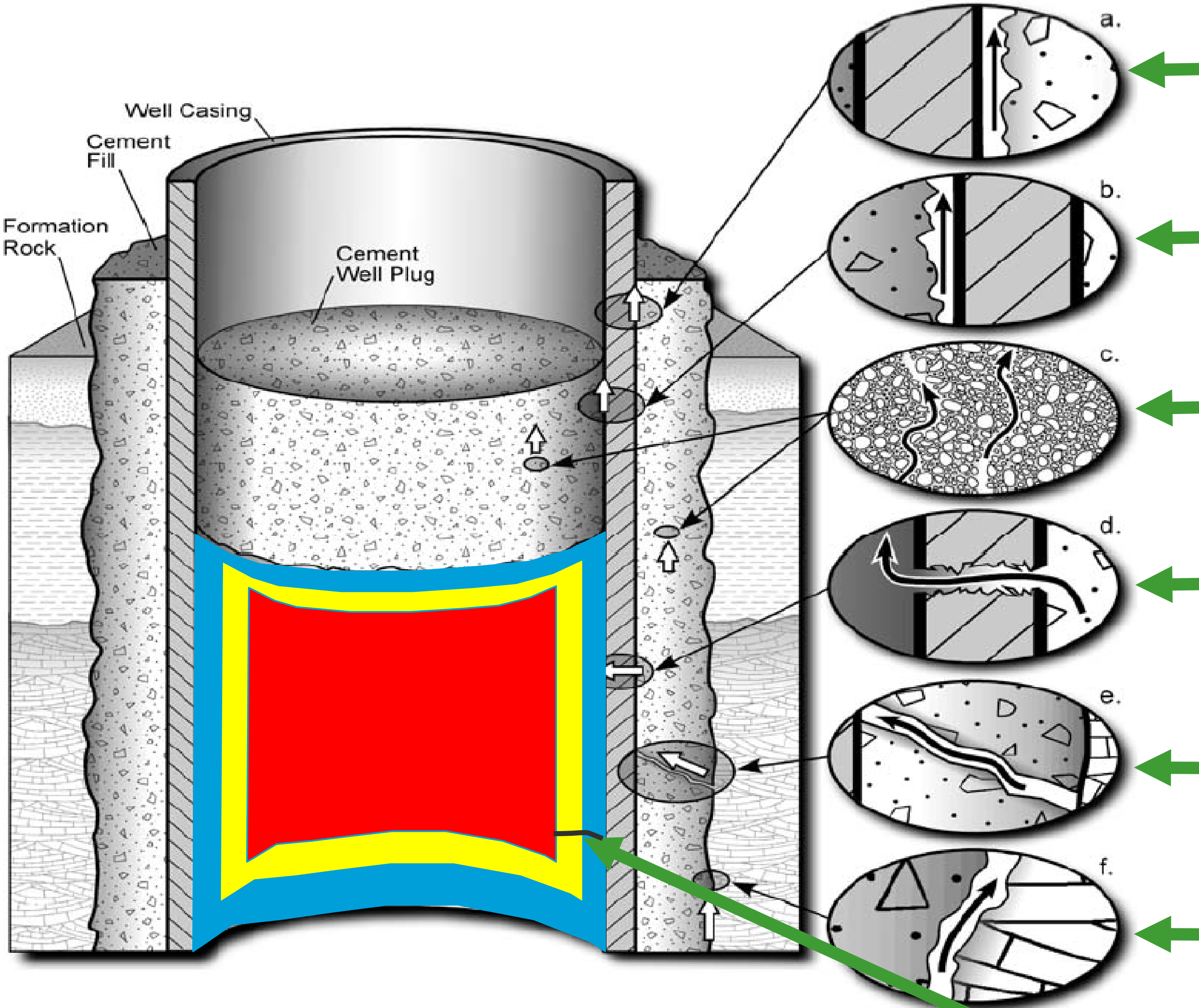


Probably not important

Need to worry about

Probably slow

Not relevant

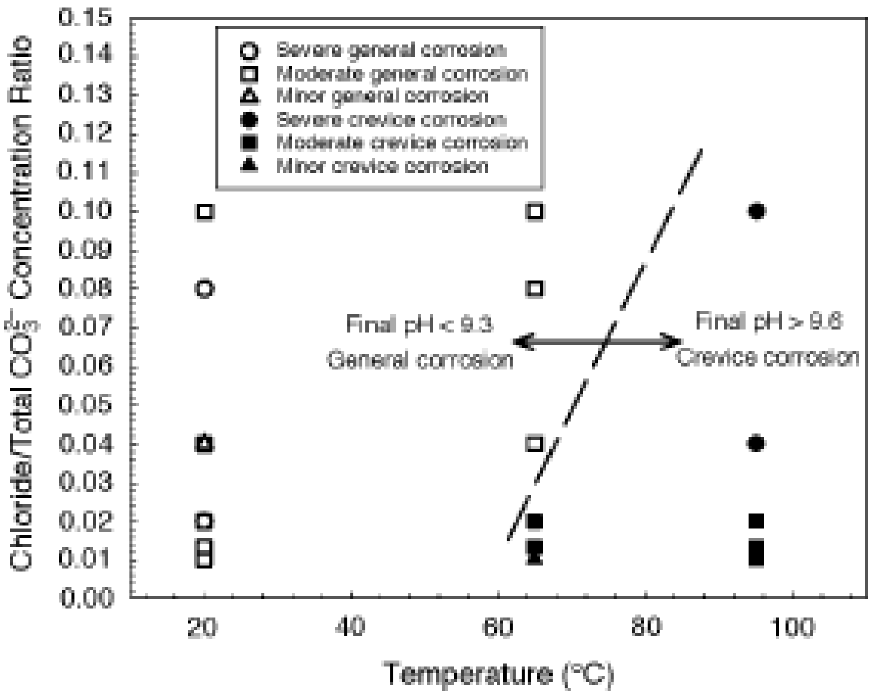
Not relevant

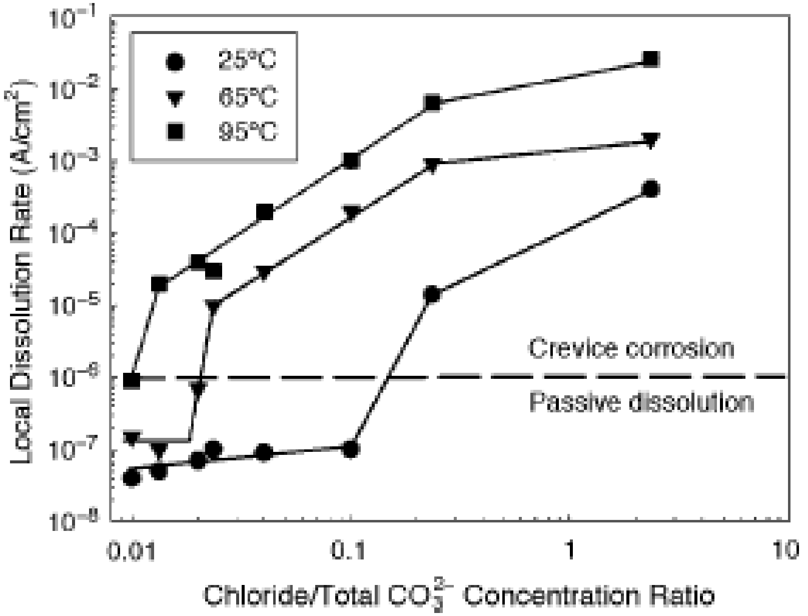
Not relevant

Figure 5.13. Possible leakage pathways in an abandoned well (after Gasda et al., 2004).

Need to worry about

Effect of pH, temperature, Cl on localized corrosion of carbon steel





Brossia and Cragnolino, Corrosion 56(10), 2000

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Experience of down hole tubulars in geothermal wells

Corrosivity class	Observations
I. Cl ~ 100,000 ppm, pH (unflashed) < 5, T > 390 F	Steel: > 1 mm/y, serious localized corrosion even for some CRA*
II. Cl ~ 1000 – 10,000 ppm, pH <<4.5, T 250 – 350 F	Steel: in separated liquid: 0.5 – 0.7 mm/y, some localized corrosion
III. Cl: 5000 – 20,000 ppm, pH: 5-6, T: 300 – 375 F	Steel: 0.125 to 0.25 mm/y Some localized corrosion
IV. Cl: 250 – 10,000 ppm, pH >5, T: 250 – 390 F	Steel: <0.125 mm/y; minor pitting
Va: Cl: 150-3500 ppm, pH ~7 T: 120 – 205 F	Steel: 0.3 mm/y; some severe pitting
Vb: Cl < 3500 ppm, pH: 8-10, T: 120 – 205 F	Some pitting

* CRA – corrosion resistance alloys

C.S. Smith and P. Ellis, 1983

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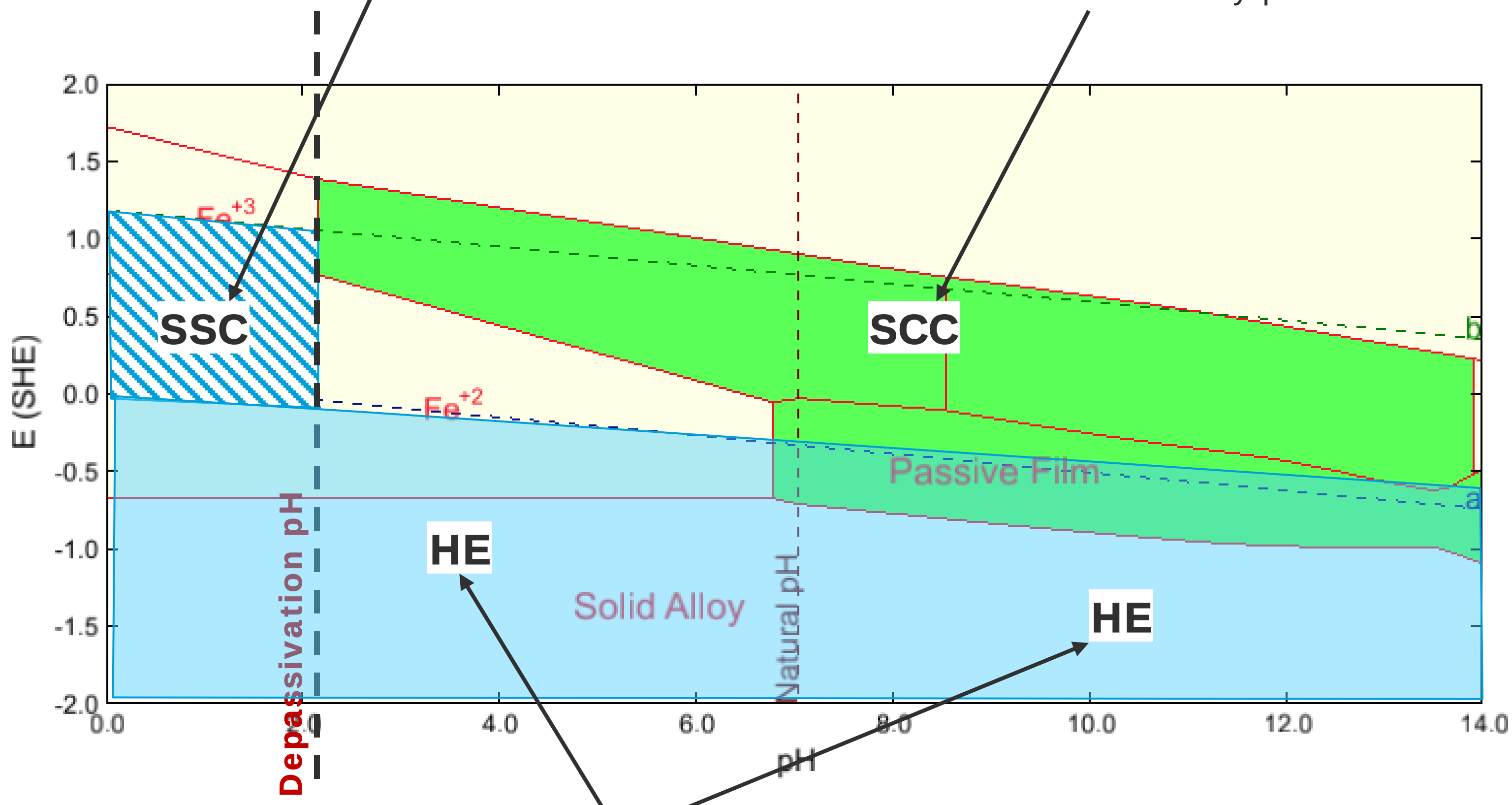
Hydrogen generated by corrosion reactions on a depassivated surface and assisted by reduced sulfur or other species

SCC controlled by local anodic dissolution under passive conditions assisted by plastic deformation



Hydrogen generated by galvanic coupling or applied potential with reduced sulfur or other species acting as hydrogen recombination poisons

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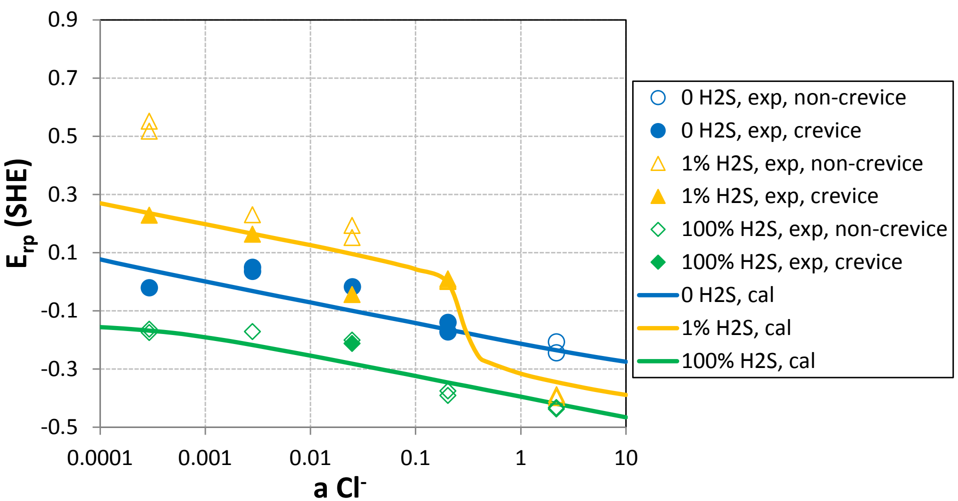
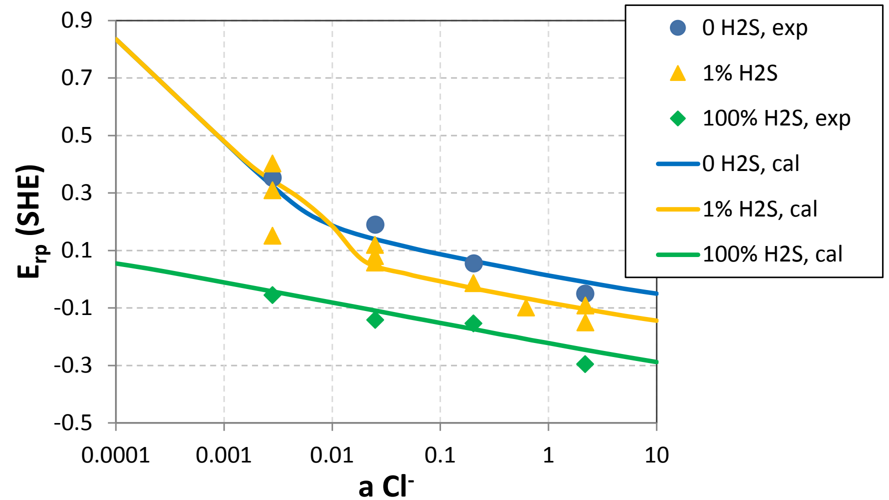
Critical potential for localized corrosion (all at 85 C)

13%Cr Super-Martensitic stainless



25%Cr Duplex stainless



- E_{rp} for 100% H_2S shifts largely in parallel to the shift for 0% H_2S
- Behavior for 1% H_2S is more complex

Anderko et al., Corrosion 2015

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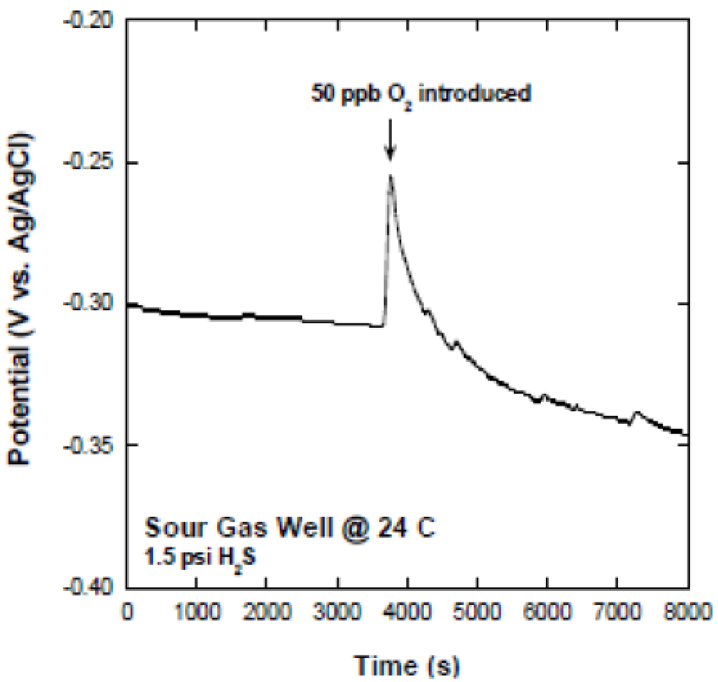
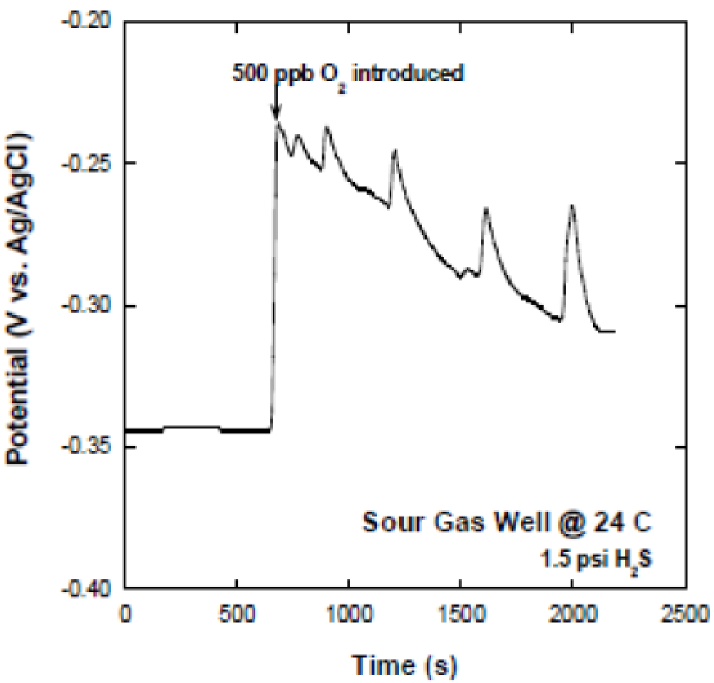
What is "anoxic" ?



a)



b)

Meck et al., Corrosion/2013, Paper 2639

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Galvanic effect between casing and container

- H_2 generation on the container
  - Creates potential for embrittlement of alloy container/capsule
- H_2 generation rate in confined space will be determined the pH increase in solution, corrosion product formation on steel, and hydrogen pressure build up

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What characteristics of EBS are important?

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Characteristics of Container

- Fracture toughness
- Thermal stability
  - E.g., avoiding formation of body centered cubic structures, Ni-base alloys with too low an iron content, etc.
- Stress corrosion cracking in borehole environment
- Localized corrosion

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Potential Issues with Capsules

- Mechanical failure
  - During insertion into borehole
  - During long-term exposure
- Environmentally assisted cracking and localized corrosion
  - Localized corrosion
  - Stress corrosion cracking
  - Galvanic effect between casing and capsule

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Mechanical failure

- The capsules are likely to be sensitized
  - Initial pour temperature was in the sensitization range
- Formation of alpha prime phase in welds of 316L
  - Ferrite transforms spinodally to alpha prime
  - Reduces toughness
- Formation of long range ordering in C-276
  - Long-range ordering can reduce toughness in extreme cases
  - Long-range ordering can also increase hydrogen embrittlement susceptibility
- Impact loading during drop in bore hole

Environmentally assisted cracking and localized corrosion

- Both salts contain significant unknown impurities – some of these can hydrolyze and decrease local pH (Al, Fe)
- Brine from the surrounding environment
- Multiple capsules placed in an over pack and gaps filled by molten Pb or SiC powder
  - SiC can galvanically couple with canisters to increase corrosion potential
  - Pb can cause embrittlement and Pb salts can cause SCC

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What is our knowledge regarding EBS characteristics?

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Are predictive tools and engineering judgements available?

- Utilize experience from oil and gas production operations
  - However, long-term performance knowledge does not exist
  - Oil & gas industry is not very proactive
- Modeling tools exist, but require further research
  - Long-term, low temperature (about 200 C) phase transformation kinetics have not been well characterized
  - Prediction of localized corrosion and SCC in brines have been successful, but require further research

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Conclusion on reliance on container

- Because of many uncertainties related to plug and capsule performance, well-designed over packs (containers) will be necessary
- The potential detrimental effects of fillers such as Pb and SiC should be assessed
- The extent of reliance on containers should be determined within the overall repository performance context

Further considerations

- Monitoring is essential to ensure that any deviation from anticipated behavior can be rectified in a timely fashion
  - Monitoring of radionuclide release alone is insufficient (e.g., at Hanford the cause of some of the leaks is still not certain after 60 years)
  - Monitoring of WP is needed to determine potential causes of failure
- Monitoring of WP in deep bore hole is difficult, especially over long time periods

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