Options for Completing the Emplacement Zone for Deep Borehole Field Disposal

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Introduction

- Four options for constructing & completing emplacement zone were developed and evaluated
- Study not specific to any location or waste form
- Study identified key uncertainties for possible investigation during deep borehole field test (DBFT)
Possible Components for Completing the EZ

- Guidance casing
- Perforations
- Emplacement fluid (not shown)
- Cement
Some Factors Affecting EZ Options

- Characteristics of waste packages (WPs)
- Need to place WPs in intervals
- Affects on EZ caused by thermal pulse, from decay heat from the wastes
- Generation of hydrogen gas
Characteristics of Generic WPs

- One of the conceptual WP designs
WPs Must be Placed in Intervals

- Must limit compressive stress on bottom WP
- Place intervals of 40 or fewer WPs (~200 m)
- *Weight of each interval must be transferred to borehole wall*
Decay heat from waste will create thermal pulse

Conservatively, at 3 km, $140^\circ C$ temperature rise above ambient

Thermal pulse < 100 years

Effects of thermal pulse:
- Emplacement fluid expands ~ 5% to 20% in volume, possible great stresses
- Steel expands ~ 0.1% to 0.16%, possible great stresses
Hydrogen Gas after Emplacement

- $3\text{Fe}_{(cr)} + 4\text{H}_2\text{O} \leftrightarrow \text{Fe}_3\text{O}_4(s) + 4\text{H}_2(g)$
- SKB (2014) calculated equilibrium partial pressure at 15,700 psi at 100° C
- Issue requires additional study
- That said, some EZ configuration options are better than others
Advantages of Guidance Casing

- Clear smooth path for WP emplacement
- Keep rock / cement / junk from falling in path of WPs
- Helps dissipate surge pressure when WPs lowered
- Aligns WPs as stacked (limit offset loading)
- Facilitates placement of cement plugs if used
- Limits terminal sinking velocity, if WP accidently dropped
- Facilitate recovery of WPs in case of accident

**Key Conclusion** – all EZ options will include guidance casing
Perforations in Guidance Casing

- Perforations are necessary:
  - to equalize fluid pressure from inside guidance casing
  - for cementing
- Too many perforations, or too large, reduce advantages of guidance casing
Cement can be used several ways to construct and close EZ

- To create cement plugs to transfer weight of WPs to borehole wall
- To secure casing and prevent thermal expansion
- At closure, to replace emplacement fluids
  - No fluids to expand
  - Limited water for hydrogen gas generation
## Four Options for Construction and Completing EZ

<table>
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<tr>
<th>Option</th>
<th>Pre-Installed Perforations</th>
<th>Guidance Casing Install</th>
<th>In-Situ Perforations</th>
<th>WP Emplacement</th>
<th>Cement Plug Installations / Cementing</th>
<th>Final Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>One 2 cm diameter every 50 m</td>
<td>Hang casing in fluid-filled borehole</td>
<td>Large perforations at top of each cement plug</td>
<td>200 m stack of WPs</td>
<td>Set bridge plug, set 10 m thick cement plug by gravity overflow inside guide casing and flowing into rock annulus, clean out casing</td>
<td>Perforated guide casing, closure fluid between rock &amp; guide casing &amp; between guide casing and WPs, 10 m cement bridge plugs ~ 200 m apart</td>
</tr>
<tr>
<td>2</td>
<td>One 2 cm diameter every 50 m</td>
<td>Hang casing in fluid-filled borehole</td>
<td>Large perforations at bottom of each cement plug</td>
<td>200 m stack of WPs</td>
<td>Set bridge plug, set squeeze package 10 m higher, and inject cement into this plug interval and through perfs. into the annulus</td>
<td>Perforated guide casing, closure fluid between rock &amp; guide casing &amp; between guide casing and WPs, 10 m cement bridge plugs ~ 200 m apart</td>
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<tr>
<td>3</td>
<td>none</td>
<td>Hang casing in fluid-filled borehole, fully cement to borehole wall, bottom up</td>
<td>Perforate at intervals for pressure relief only, then mill out inside of casing</td>
<td>200 m stack of WPs</td>
<td>Set bridge plug, plus 10 m thick cement plug inside casing by gravity placement, then clean out casing</td>
<td>Solid guide casing, cement between rock and guide casing full length, fluid between WPs and guidance casing, with 10 m cement plugs ~ 200 m apart inside guidance casing</td>
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<tr>
<td>4</td>
<td>none</td>
<td>Perforate at bottom of each 200 m interval</td>
<td>Large perforations at bottom of each stack interval, mill out inside casing</td>
<td>200 m stack of WPs</td>
<td>Set squeeze packer at top WP interval, injected cement through packer in annulus between WPs &amp; guidance casing - cement travel down WP interval &amp; up between rock and casing annulus</td>
<td>Guide casing fully cemented, with cement between rock &amp; guide casing &amp; cement between guide casing and WPs</td>
</tr>
</tbody>
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Option 1 Overview

- Base case design, Arnold, et al., 2011
- 13 3/8 inch guidance casing in tension before emplacement
- 2 cm perforation every 50 m
- 37 WPs per interval
- Set 10 m cement plug above each interval, to hold weight of next interval
- At closure: 9 intervals of WPs, separated 10 m cement plug
- At closure: fluid between WP and casing, and fluid between casing and formation
Option 1 Diagram

- Guidance casing
- Emplacement fluid (not shown)
- Waste package
- Perforations
- 10 m cement plug
- Bridge plug
- 37 Waste packages
13 3/8 inch guidance casing

Guidance casing in tension before emplacement

No perforations

39 WPs per interval

Cement each interval of WPs (inside and outside) as shown in diagram

At closure: WPs cemented in guidance casing, and guidance casing is cemented to formation

Advantages fully cemented interval: holds weight of next interval of WPs, prevents expansion of steel guidance casing, removes liquids (thermal and H2)
Option 4 Diagram

- Guidance casing
- Squeeze Packer
- 39 Waste packages
- Perforations
- 39 Cemented waste packages
Key Uncertainties

Key uncertainties for possible investigation during the filed test:

- Affect of perforations on terminal velocity WPs
- Cementing options
Summary

- Four options for constructing & completing EZ developed
- Generic: not specific to any location or waste form
- Key conclusion: guidance casing should be used
- Key uncertainties: affects of perforations, cementing options