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Used Fuel Disposition Campaign

Emplacement Zone Completion Options for Deep Borehole Field Disposal

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Introduction

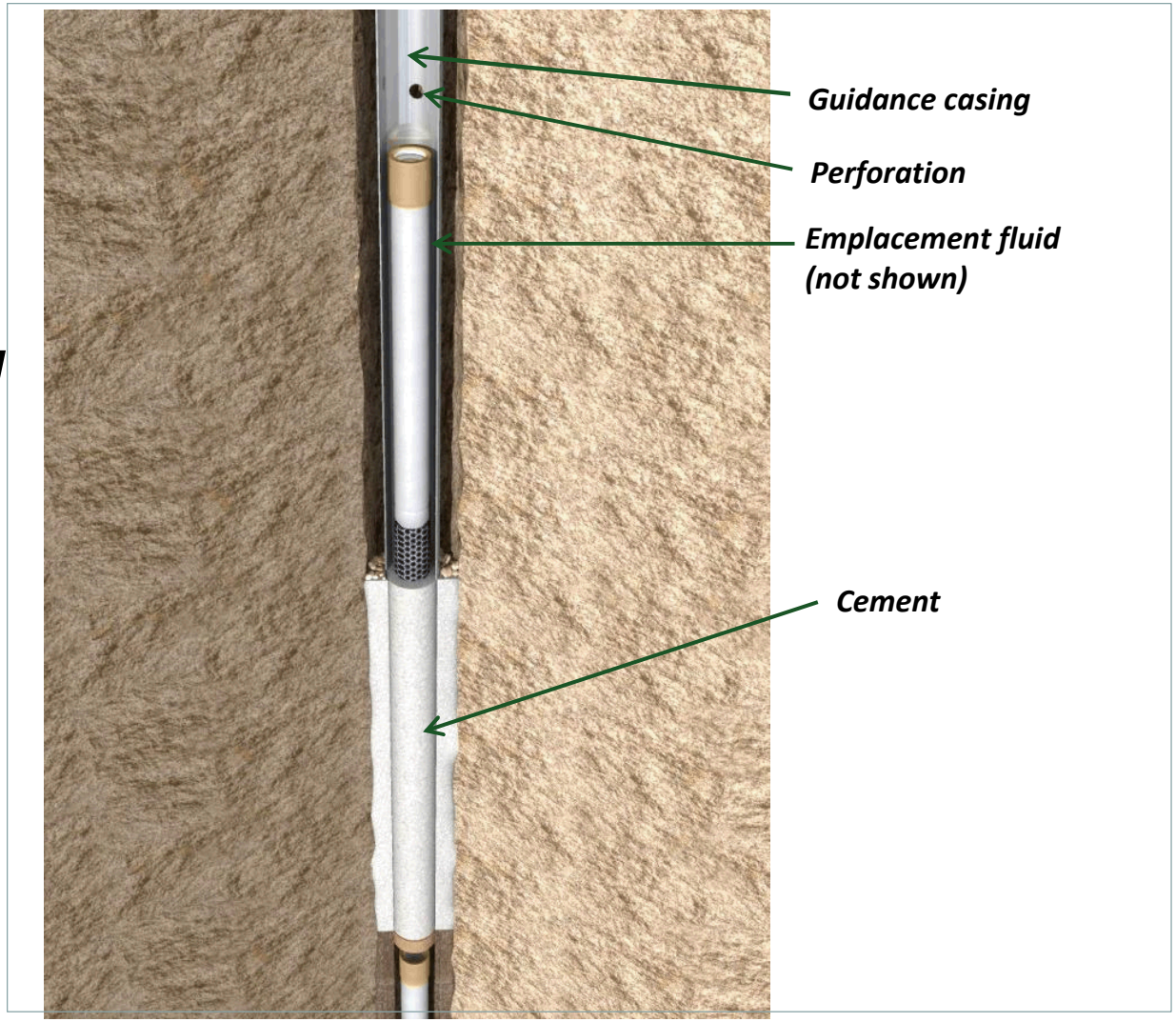
- Four options for constructing and completing emplacement zone (EZ) were developed and evaluated
- Study was not specific to any location or waste form
- Study identified key uncertainties for possible investigation during the deep borehole field test (DBFT)

The Emplacement Zone

- *Zone where wastes will be emplaced*
- *3 km - 5 km depth*
- *17 inches in diameter*
- *Crystalline rock*
- *Fluid filled*

Possible Components for Completing the EZ

- *Guidance casing*
- *Perforations in casing*
- *Emplacement fluid*
- *Cement*



Factors Affecting EZ Options

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

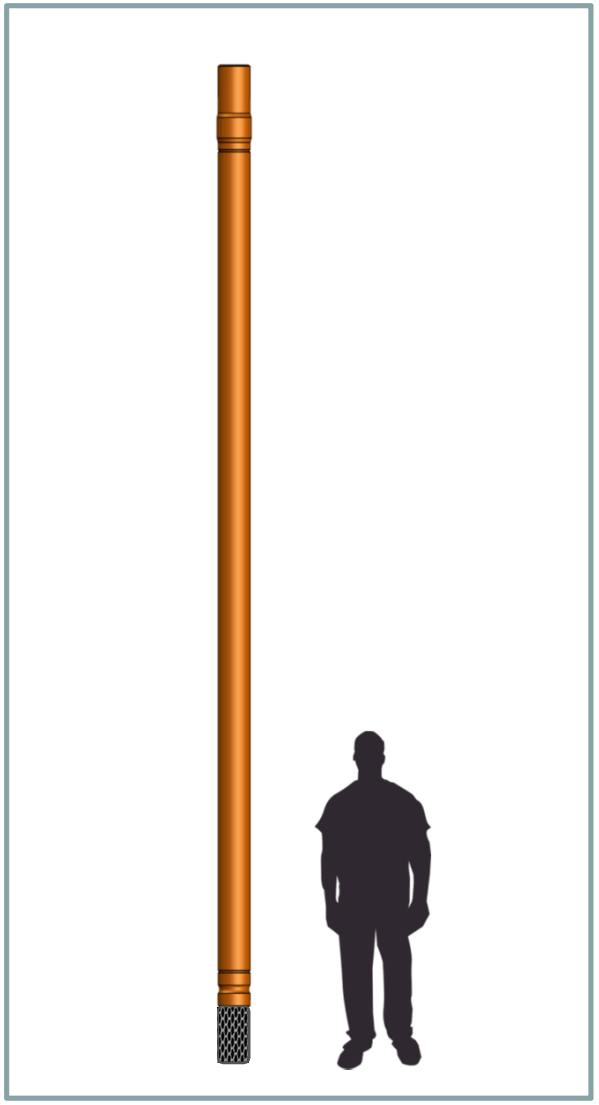
Initial Conditions in Generic EZ

- 4 points: temperature, pressure, fracturing, broad range

Initial Generic Conditions in EZ	3 km (9,840 ft) top of EZ	5 km (16,400 ft) bottom of EZ
Ambient Temperature	110°C (230°F)	170°C (340°F)
Lithostatic Pressure	10,330 psi	17,900 psi
Hydrostatic Pressure in Formation	4,690 psi	8,385 psi
Hydrostatic Pressure in Borehole Fluid (1.3 gm/cc)	5,540 psi	9,650 psi
WP designed compressive stress	9,650 psi	9,650 psi
Predicted Fracture Pressure (at 0.7 psi/ft)	6,900 psi	11,500 psi
Light weight cement (0.70 psi/ft for full column height)	6,900 psi	11,500 psi

Characteristics of Generic WPs

- One of the conceptual WP designs



WPs Must be Placed in Intervals

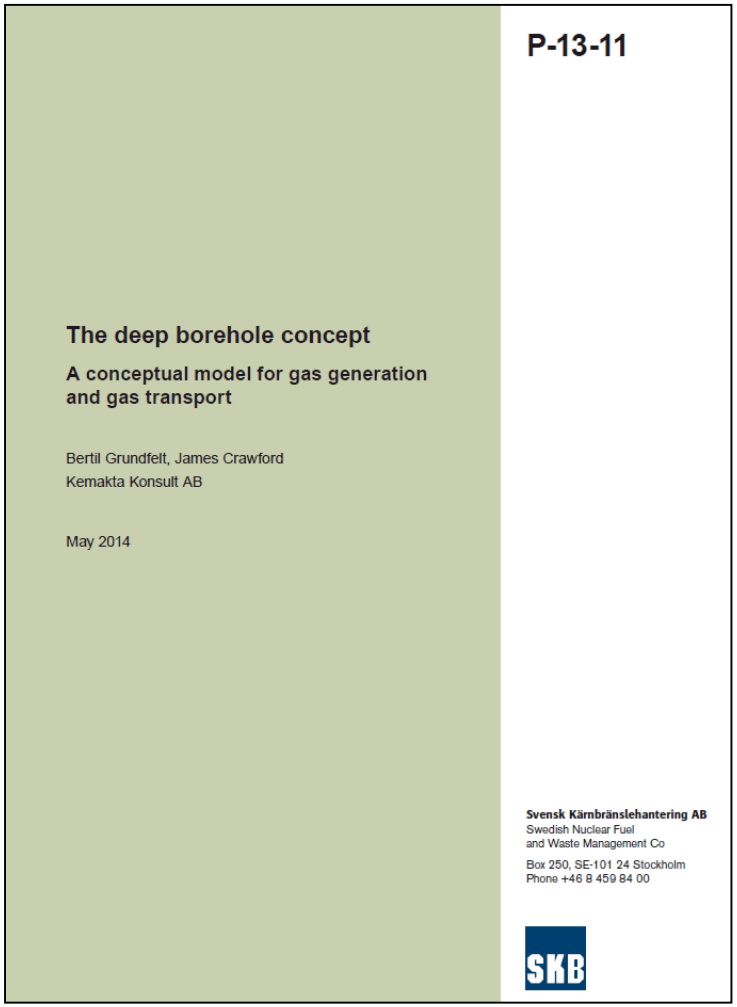
- **To limit compressive stress on bottom WP, the WPs s must be placed in intervals**
- ***Weight of each interval must be transferred to borehole wall***
- **40 or fewer WPs per interval**

Thermal Pulse After Emplacement

- Decay heat from waste will create thermal pulse
- Conservatively, at 3 km, *140° 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

- Iron + water ↔ magnetite + H_2
- $3Fe_{(cr)} + 4H_2O \leftrightarrow Fe_3O_{4(s)} + 4H_{2\,(g)}$
- Grundfelt and Crawford (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

- 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 reduce advantages of guidance casing

Cement

- 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*

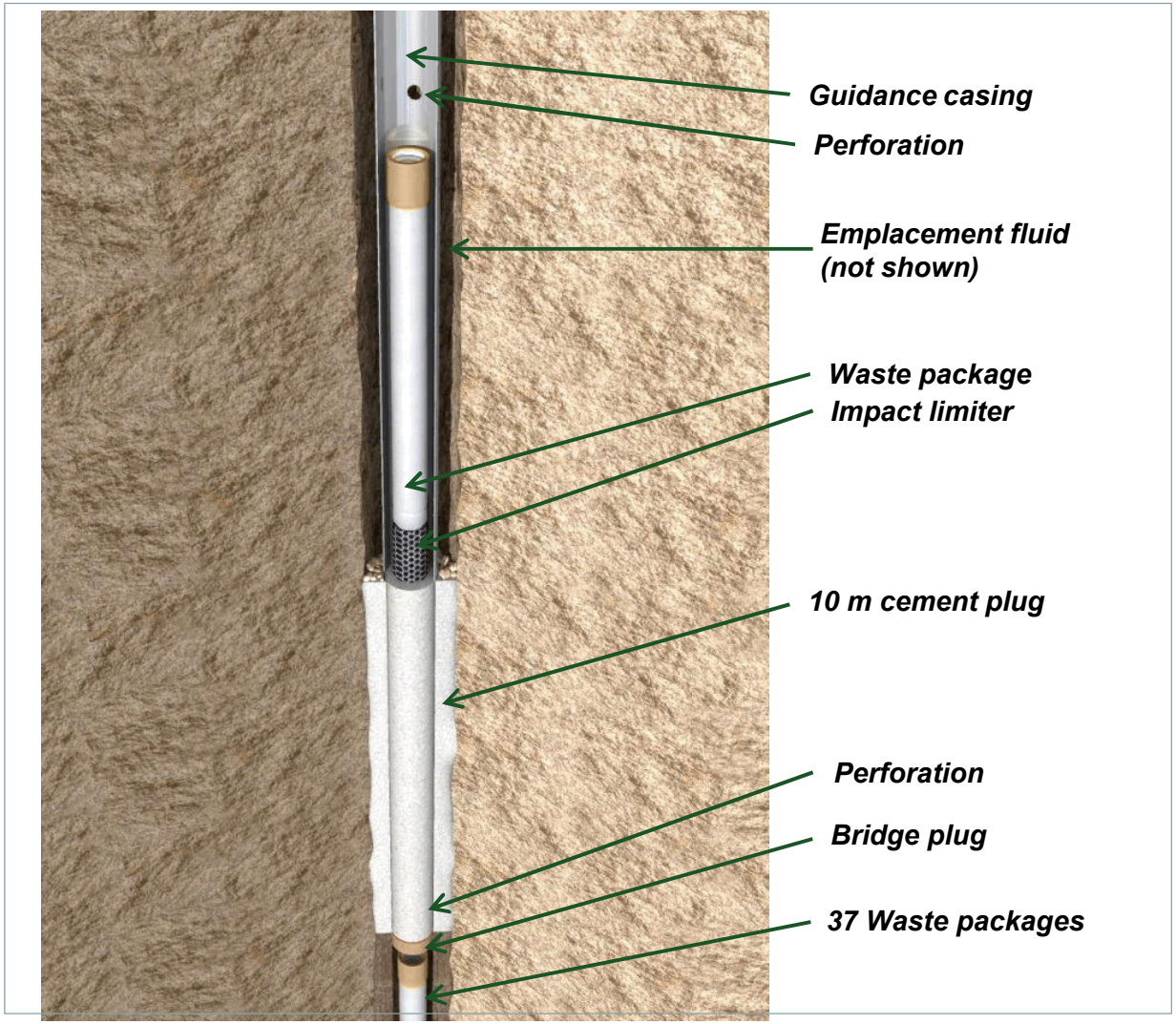
Four Options for Construction and Completing EZ

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

Option 1 Overview

- Base case design, Arnold, et al., 2011
- Emplacement fluid in borehole
- 13 $^{3}/_{8}$ inch guidance casing from surface to TD
- Guidance casing in tension before emplacement
- 2 cm perforation every 50 m
- 37 WPs per interval
- Set 10 m cement plug below 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

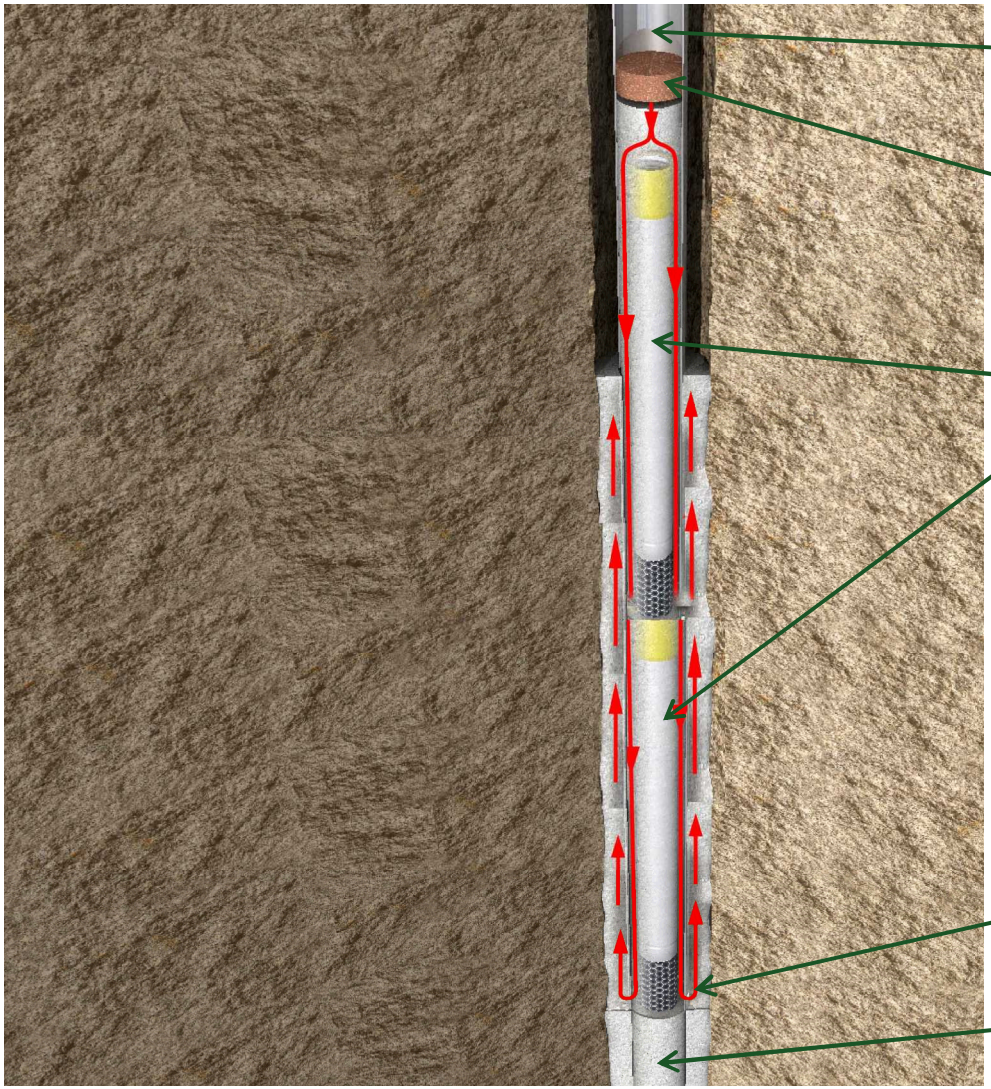
Option 1 Diagram



Option 4 Overview

- Emplacement fluid in borehole
- 13 $^{3}/_{8}$ inch guidance casing from surface to TD
- 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
- Components of EZ: Guidance casing, Perforations, Use of Cement and Emplacement fluid
- EZ Options based on: initial conditions, need to place WPs in intervals, effects thermal pulse & hydrogen gas
- Guidance casing should be used
- Key uncertainties: affects of perforations, cementing options