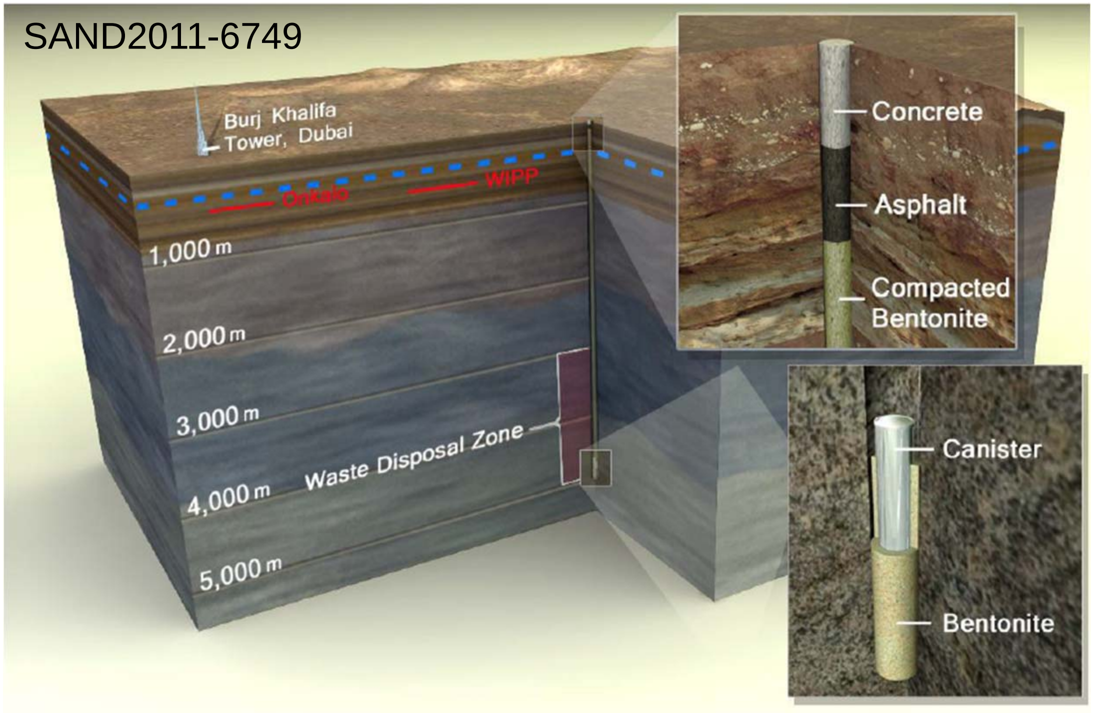
WELLBORE INTEGRITY RESEARCH PRIORITIES FOR NUCLEAR WASTE DISPOSAL IN DEEP BOREHOLES



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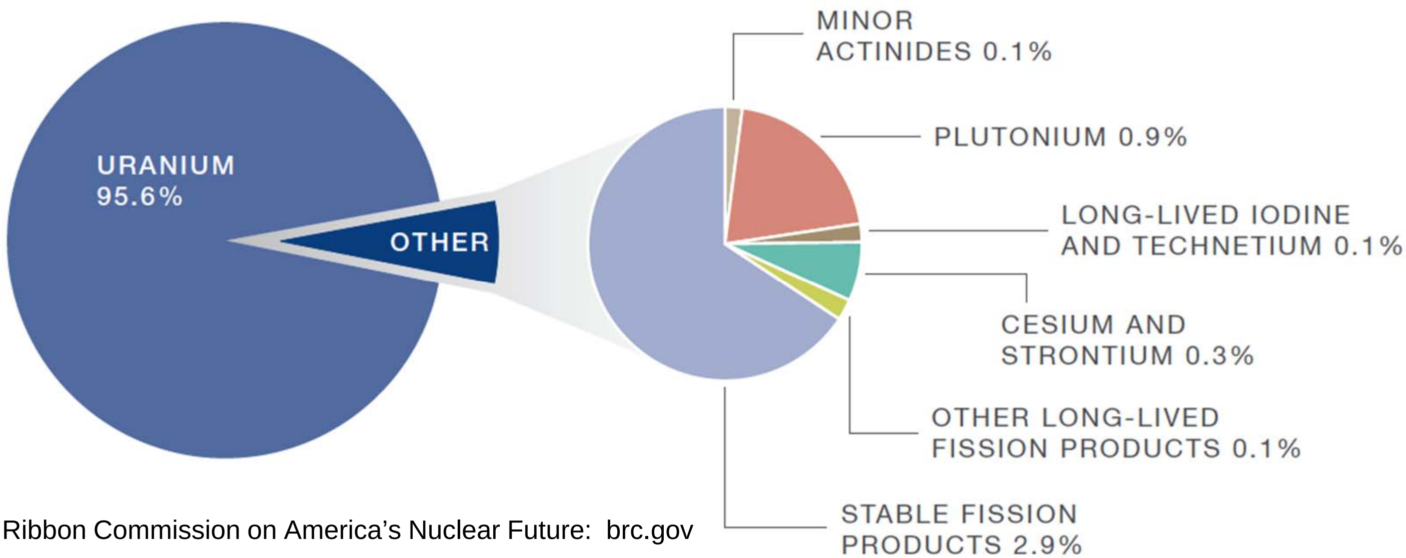
Seth Polepko, PA DEP
Doug Catalano, PA DEP

Nuclear Waste

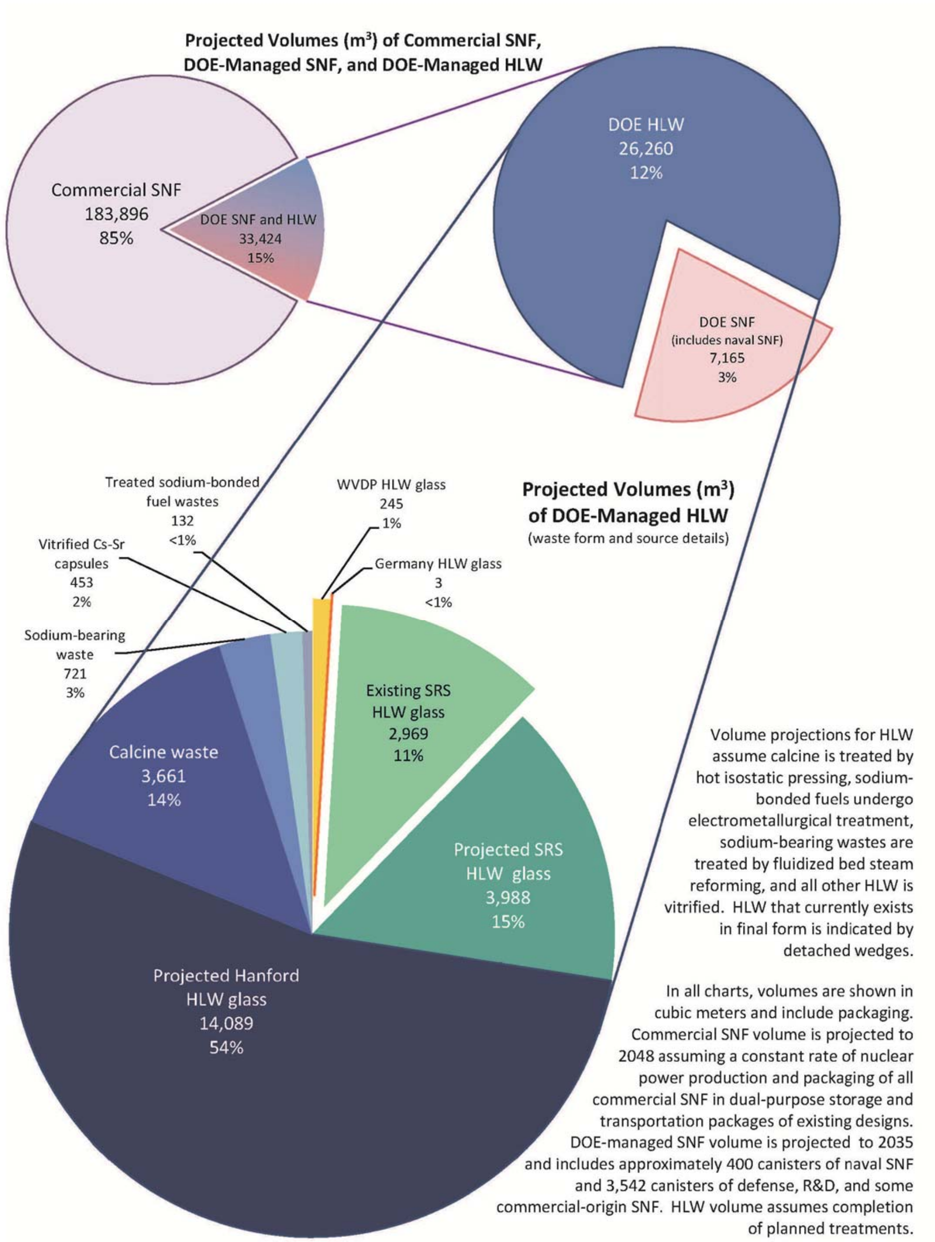
- SNF: spent nuclear fuel
  - From DOE and Navy reactors
  - Maybe commercial reactors
- HLW: high-level waste
  - Fission products
  - From processing of reactor fuels

SNF composition after 10 years



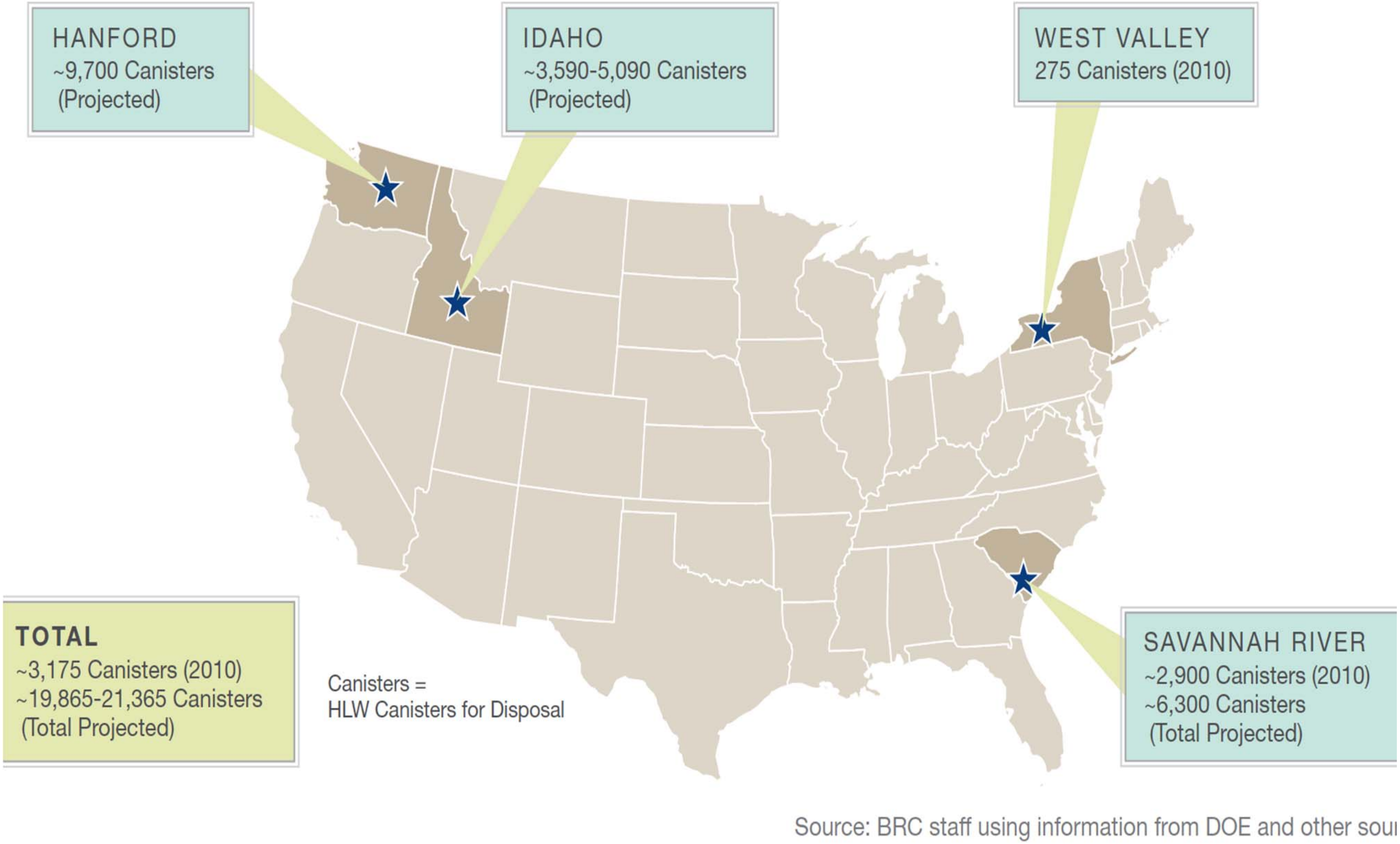
Source: Blue Ribbon Commission on America's Nuclear Future: brc.gov

HLW forms



- Vitrified HLW
  - uniform characteristics for disposal
- Other engineered HLW forms
  - Ceramic and metal wastes from treatment of sodium bonded fuels
- Salts, granular solids, and powders
  - Calcine HLW at INL

DOE High-Level Waste



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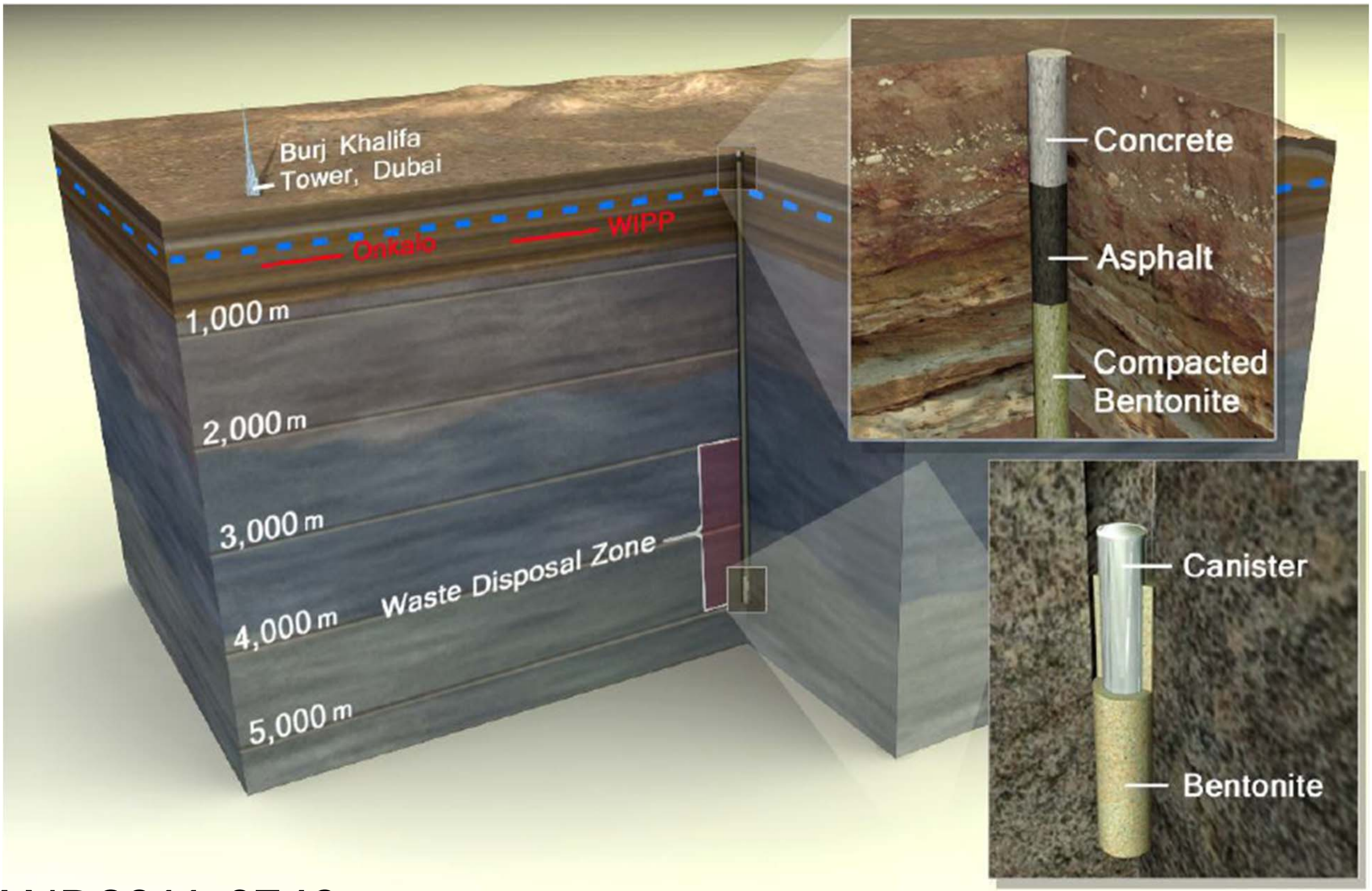
Deep Wellbore HLW Disposal: Current Concept



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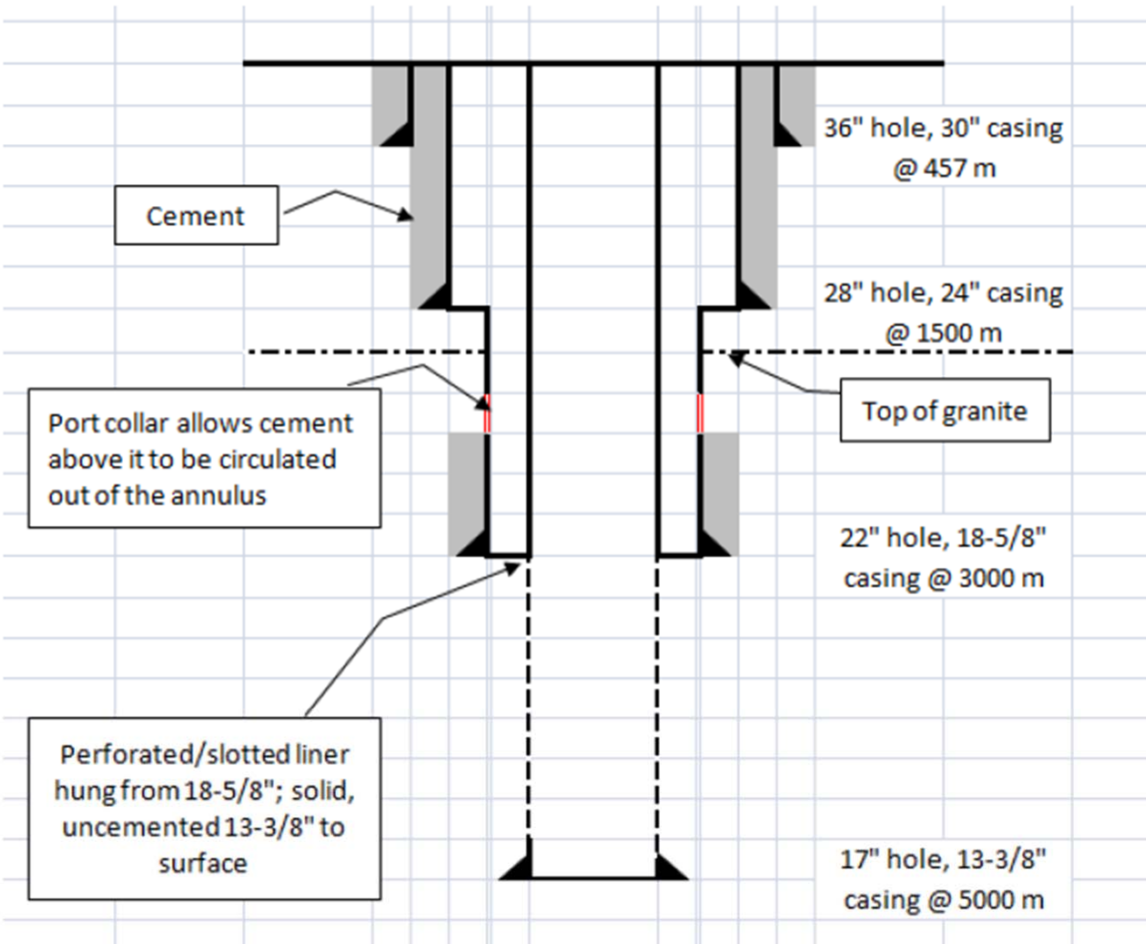
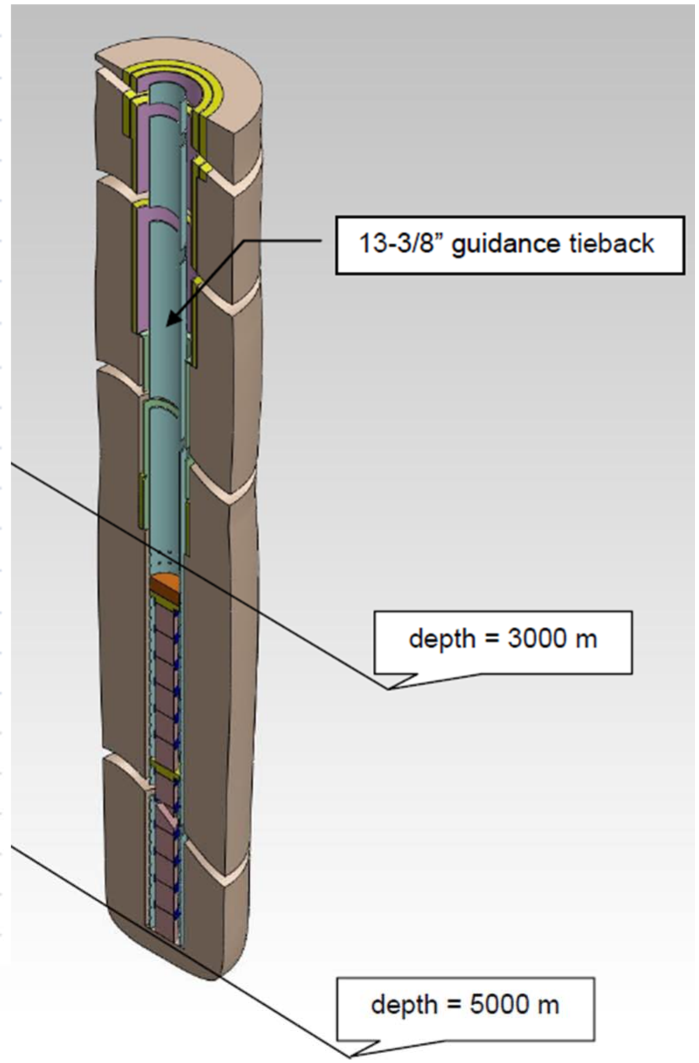
Deep Wellbore HLW Disposal: Current Concept





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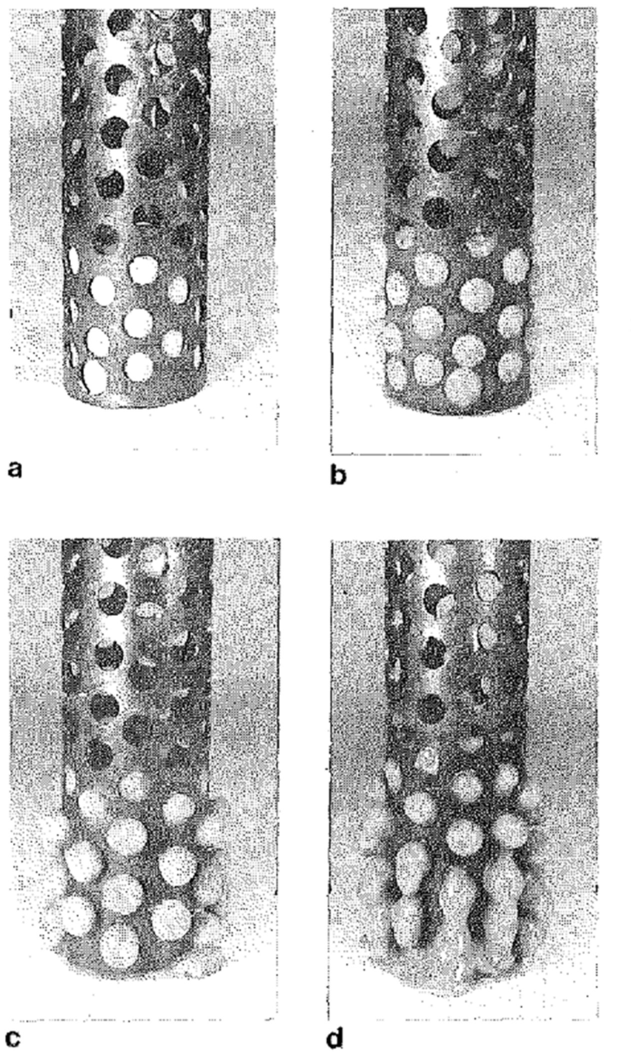
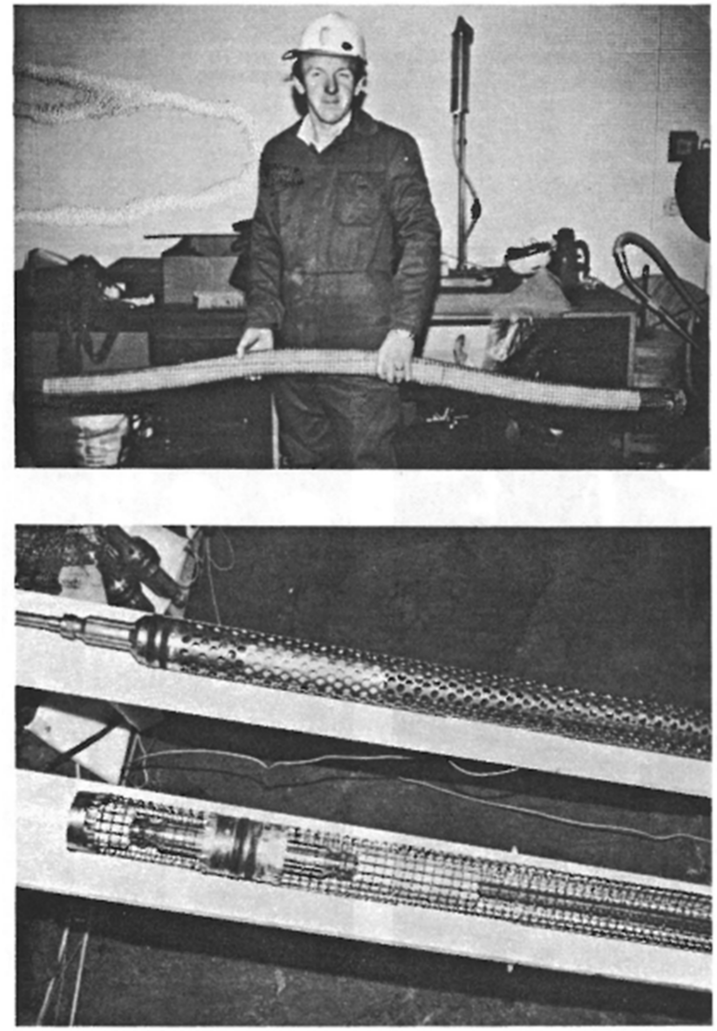
Plugging with Bentonite



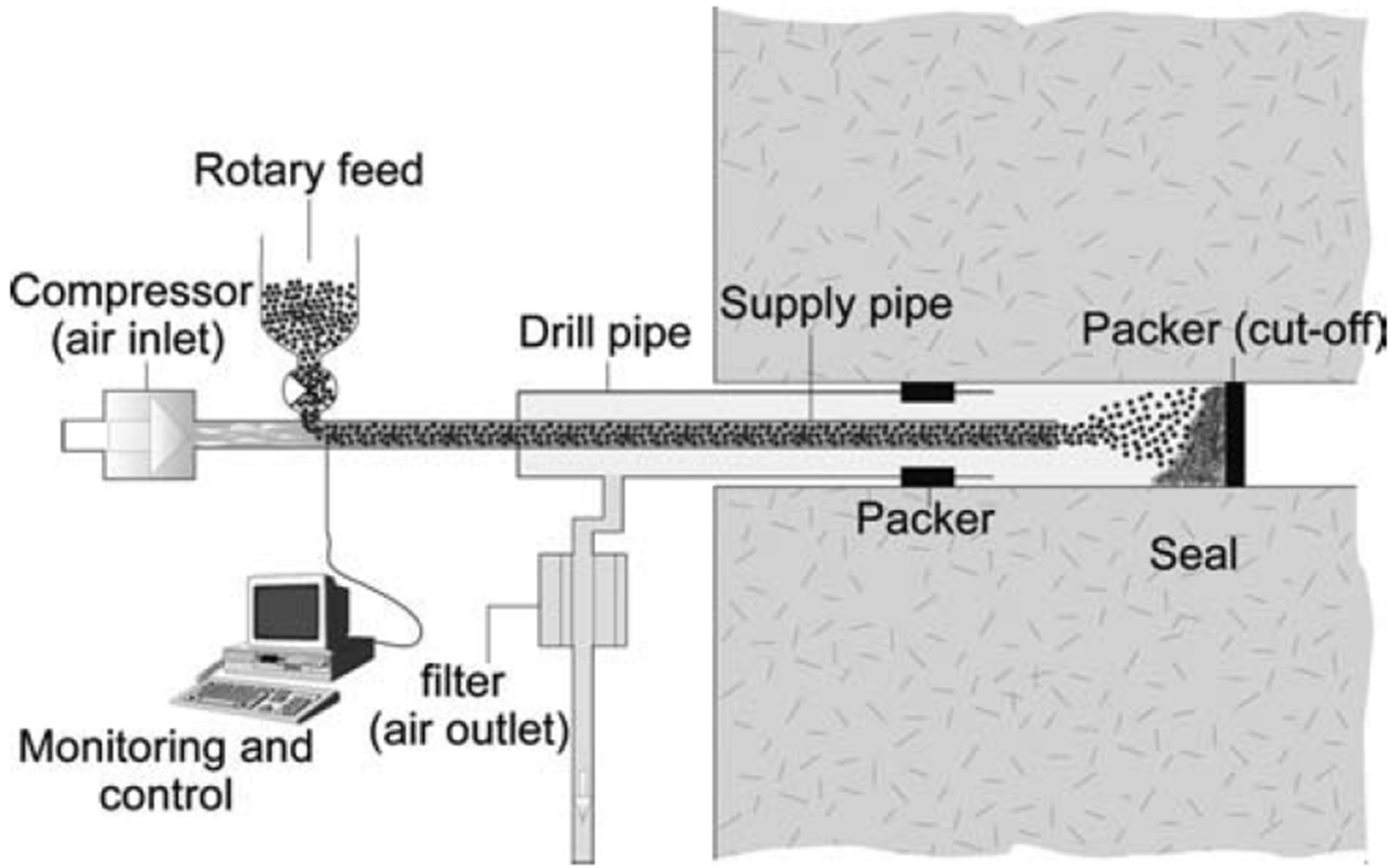
Pusch, R. (1983). Borehole sealing for underground waste storage. *Journal of geotechnical engineering*, *109*(1), 113-119.

Pusch, R. (1981). *Borehole sealing with highly compactd Na bentonite*. Kaernbraenslesaekerhet, Stockholm (Sweden).



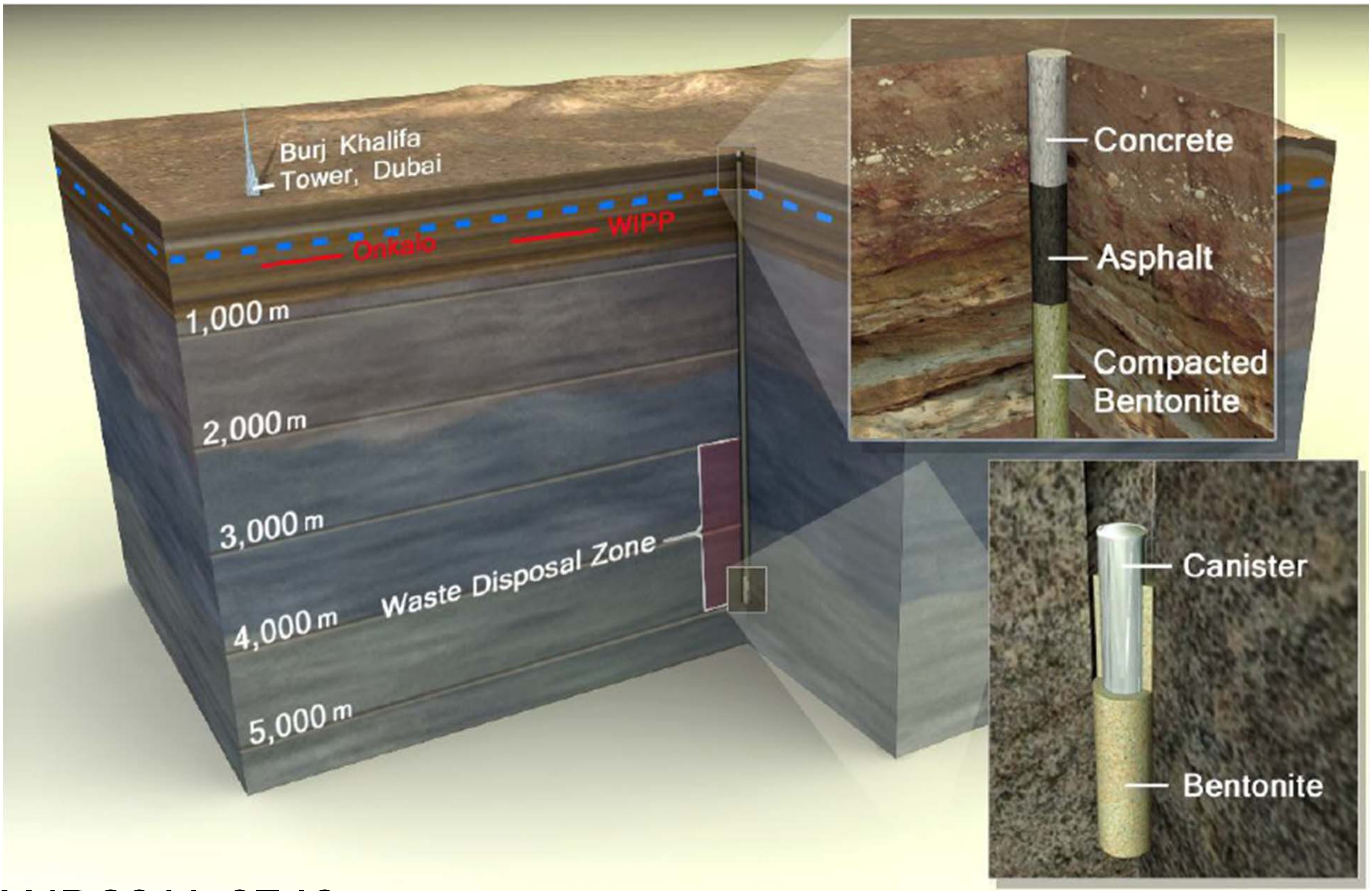
Borgesson, L., & Ramqvist, G. (1987). *Final Report of the Borehole, Shaft, and Tunnel Sealing Test-Volume 1: Borehole Plugging*. Swedish Nuclear Fuel and Waste Management Company.

Plugging with Bentonite



Blümling, P. (2005). Borehole sealing project at the Grimsel test site. Geotechnical & Geological Engineering, 23(6), 843-858.

Deep Wellbore HLW Disposal: Current Concept



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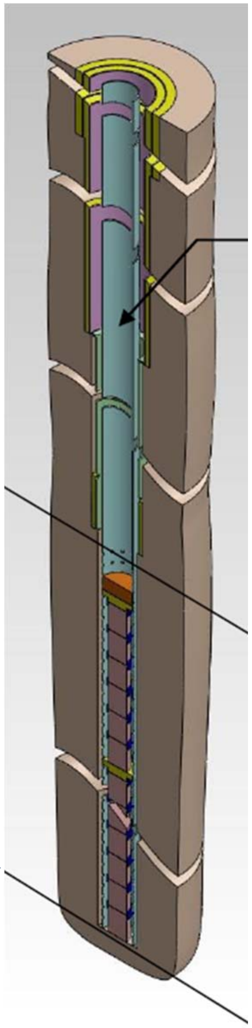
Preferred Site Characteristics for Planned DOE Field Experiment (modified from 10/24/2014 RFI)

- Topographically flat, <2km to basement rock
- Away from urban and/or petroleum activities
- Not too hot and not already contaminated
- Low probability of earthquakes or volcanos
- No known major faults or shear zones in basement rock

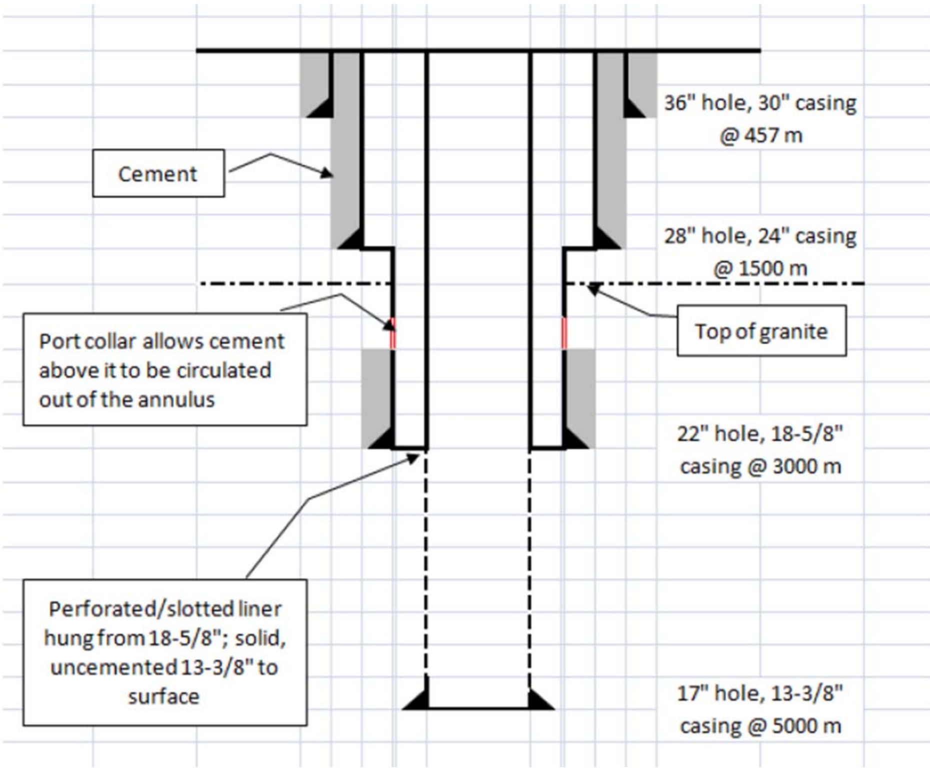


One may wish to add...

- Not too overpressured (Geodynamics 3-4km deep geothermal wells in Australia were ~5000 psi (35 MPa) overpressured relative to hydrostatic)
- Differential stresses low (to help wellbore stability)

Intention of Design

- "Cap rock" concept which works as long as
  - Permeability of top 1km of basement rock is low and as expected
  - Well seal in top 1km of basement rock results in permeability less than or equal to the rock

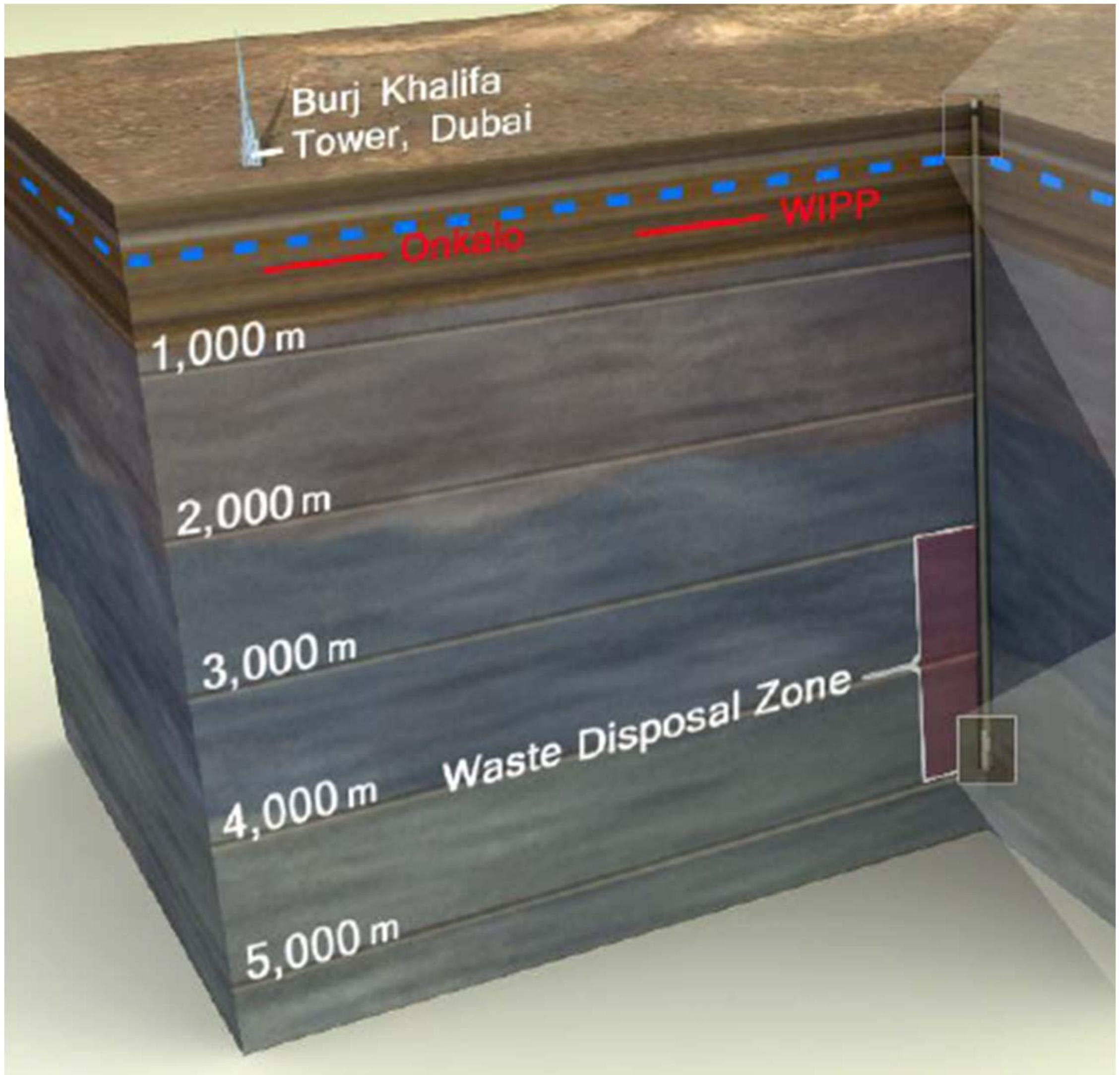


- And it is ostensibly insensitive to
  - Drilling/heating induced damage of rock below cap
  - Cement flow/seal behind lower casing/liner
  - Long term corrosion resistance casing/liner

(though latter 2 are important for ~30" groundwater string)

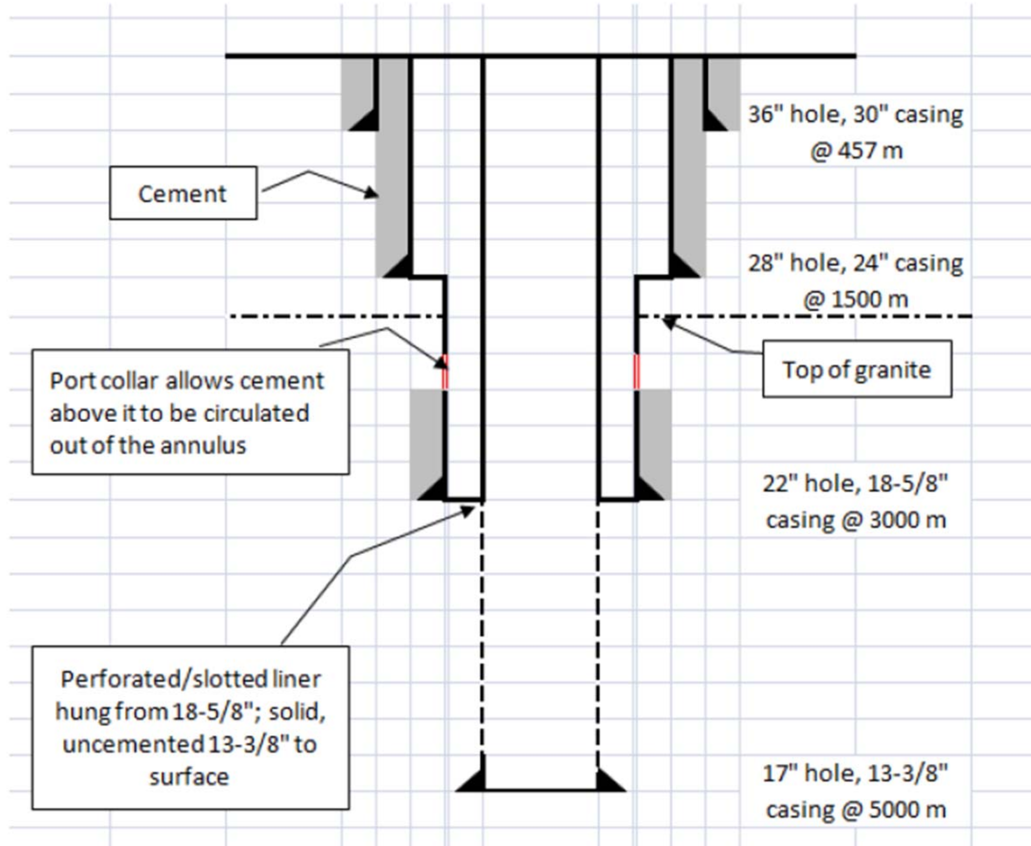
Critical Points (1 of 2)

- Wellbore stability during drilling and removal of intermediate string
- Casing/liner and canisters that withstand stresses and corrosion during construction and emplacement (~0.5-2 years)



Critical Points (2 of 2)

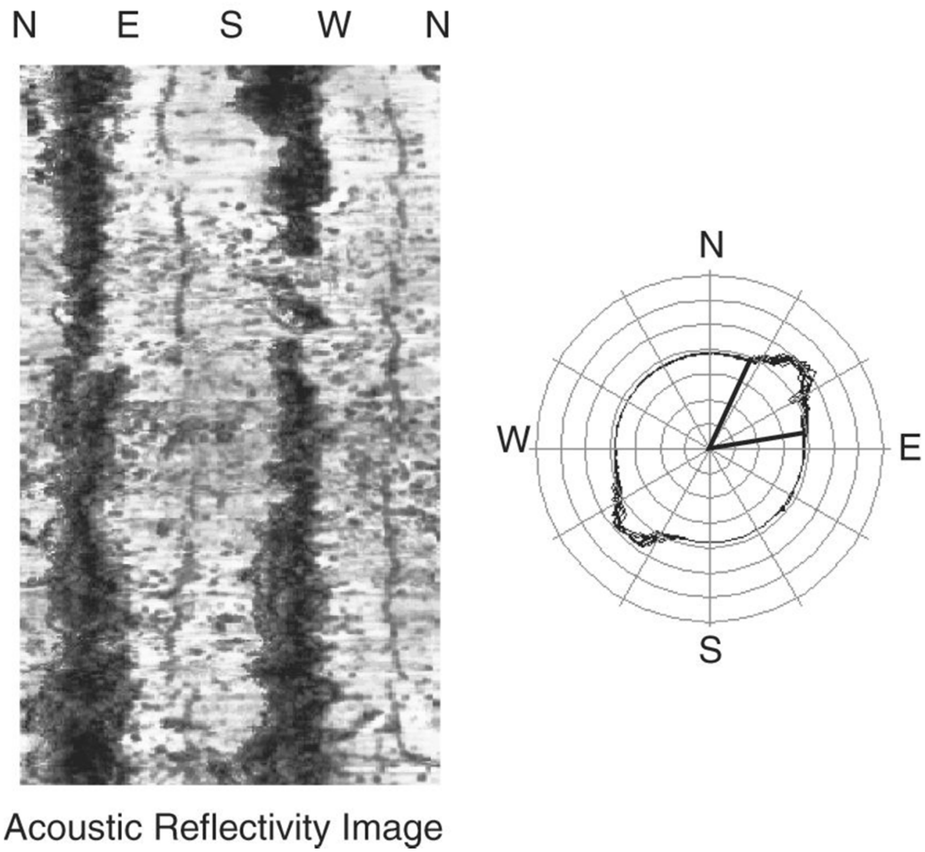
- Plug that is low enough perm, strong enough, effective even with poor hole conditions
- Fluid in emplacement zone able to dissipate into rock as it heats
- Heating and accompanying pore pressure increase does not damage “cap rock” or drive appreciable upward flow

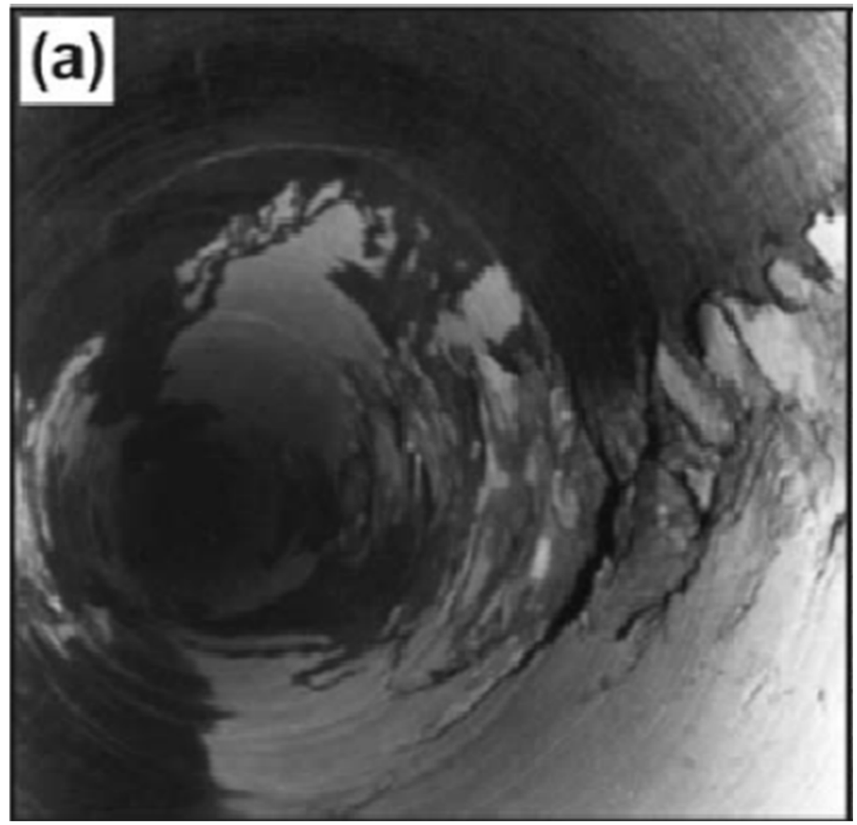


Root of the problems…

- Wellbores concentrate stresses
- Flowing materials follow path of least resistance
- Completions materials interact with surrounding environment (and surrounding environment will be changing)
- Heating expands materials

Wellbores concentrate stresses



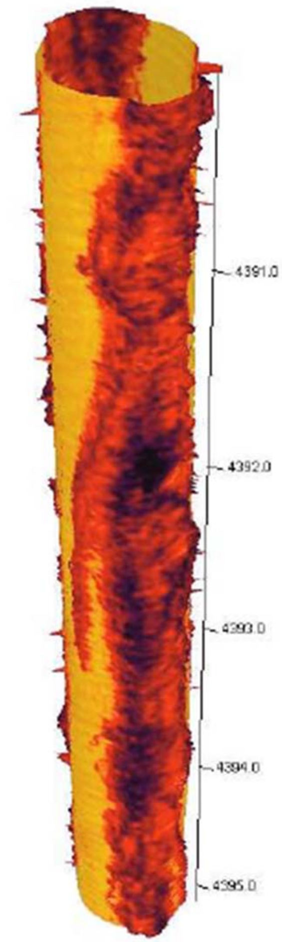


http://petrowiki.org/images/3/3f/Devol2_1102final_Page_026_Image_0001.png

Tingay, M., Reinecker, J., & Müller, B. (2008). Borehole breakout and drilling-induced fracture analysis from image logs. World Stress Map Project Stress Analysis Guidelines, 1-8.

Problems for Deep Borehole NW Storage from Breakouts

- Stuck drill pipe
- Deflection of well trajectory
- Preventing retrieval/milling of intermediate casing to expose rock to plug
- Potential for channels that are not plugged

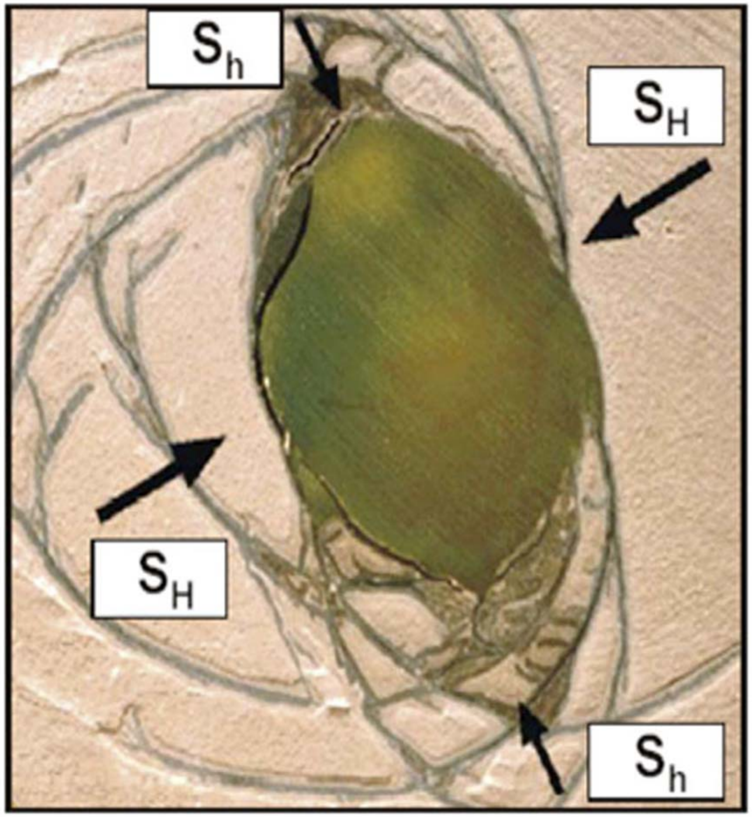


Breakouts in Basel, Switzerland Geothermal Well

Beswick, J. 2008. *Status of Technology for Deep Borehole Disposal*. Contract No. NP 01185. EPS International.

Because wellbores concentrate stresses and flow follows path of least resistance

- Enabling drilling at higher mud pressures – “wellbore strengthening”
- Characterizing stress, pore pressure, and fractures in proposed targets
- Developing/proving alternate or novel sealing approaches that are more robust to non-ideal holes
- Predicting induced stresses during emplacement of clay seals at depth



Heidbach et al. 2008. World Stress Map.

Synopsis in this month’s JPT: **Pushing the Frontier Through Wellbore Strengthening,** https://www.spe.org/jpt/article/7620-pushing-the-frontier-through-wellbore-strengthening/

Completions materials interact with surroundings

Coal String Example

Courtesy of Doug Catalano, PA DEP, presented at North American Wellbore Integrity Workshop, Pittsburgh, 11 August 2014, used with permission.

Completions materials interact with surroundings

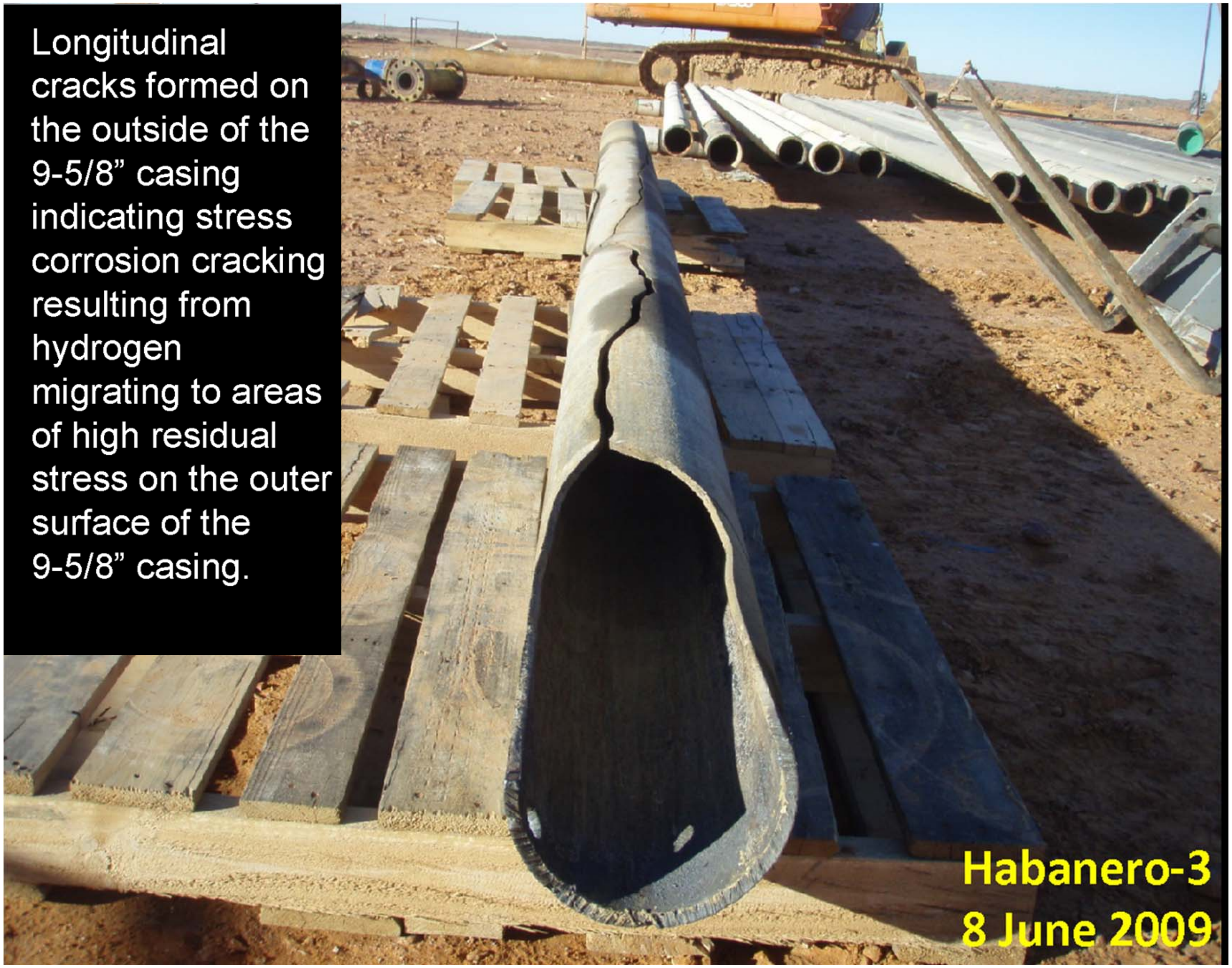
Habanero-3 Deep Geothermal Well, Australia

Source: Geodynamics presentation in Drill Well Forum, 3 Dec 2009, Brisbane, Australia
http://www.drillsafe.org.au/12-09_pres/DrillWell_Forum_Dec09_GEODYNAMICS_mike_bill_habanero_3_casing.pdf

Completions materials interact with surroundings

Habanero-3 Deep Geothermal Well, Australia

Longitudinal cracks formed on the outside of the 9-5/8” casing indicating stress corrosion cracking resulting from hydrogen migrating to areas of high residual stress on the outer surface of the 9-5/8” casing.



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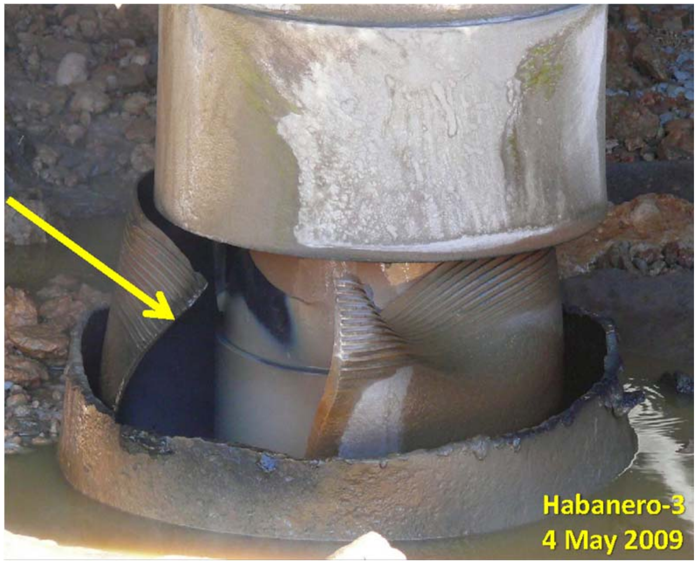
Completions materials interact with surroundings

Habanero-3 Deep Geothermal Well, Australia

18-5/8" not designed to contain reservoir pressure

18-5/8" casing rated to 4840 psi (internal yield pressure – Tenaris web site)



- Principal cause of the incident was the design and use of TN150DW steel for the two barrier strings
- Hydrogen embrittlement caused the cracks in the TN150DW casing
- H_2S may not have been the primary source of the hydrogen. The lack of corrosion by-products (iron sulphide or pyrrhotite) indicate CO_2 may have produced the hydrogen required for hydrogen embrittlement
- Siderite or iron carbonate ($FeCO_3$) was found on the surface of the 9-5/8" casing and 7" tubing.
- The corrosive reaction is:
  - $Fe + CO_2 + H_2O \Rightarrow FeCO_3$ (Siderite) $+ H_2$

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Because completions materials interact with surroundings

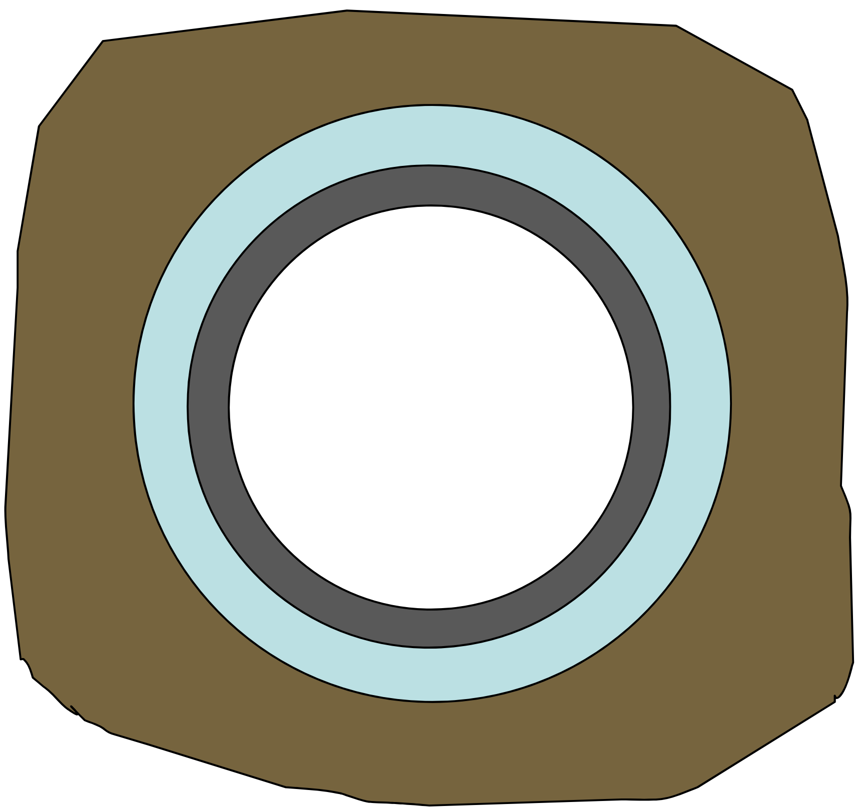
- Characterizing and predicting geochemistry
- Placement dynamics and evolving transport properties of clay-based plugging materials including mineral alteration
- Developing sealing materials that are either resistant to or resilient with respect to degradation
- Developing casing materials that are either resistant to or resilient with respect to corrosion especially during construction

Resistant: Inert to or shielded from degrading processes

Resilient: Adaptive/seal healing in response to degrading processes

Parts of completion expand at different rates

- Formation of microannulus
- Casing failure



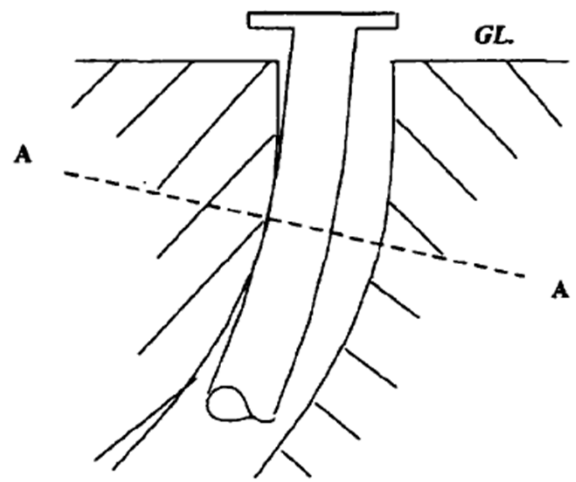


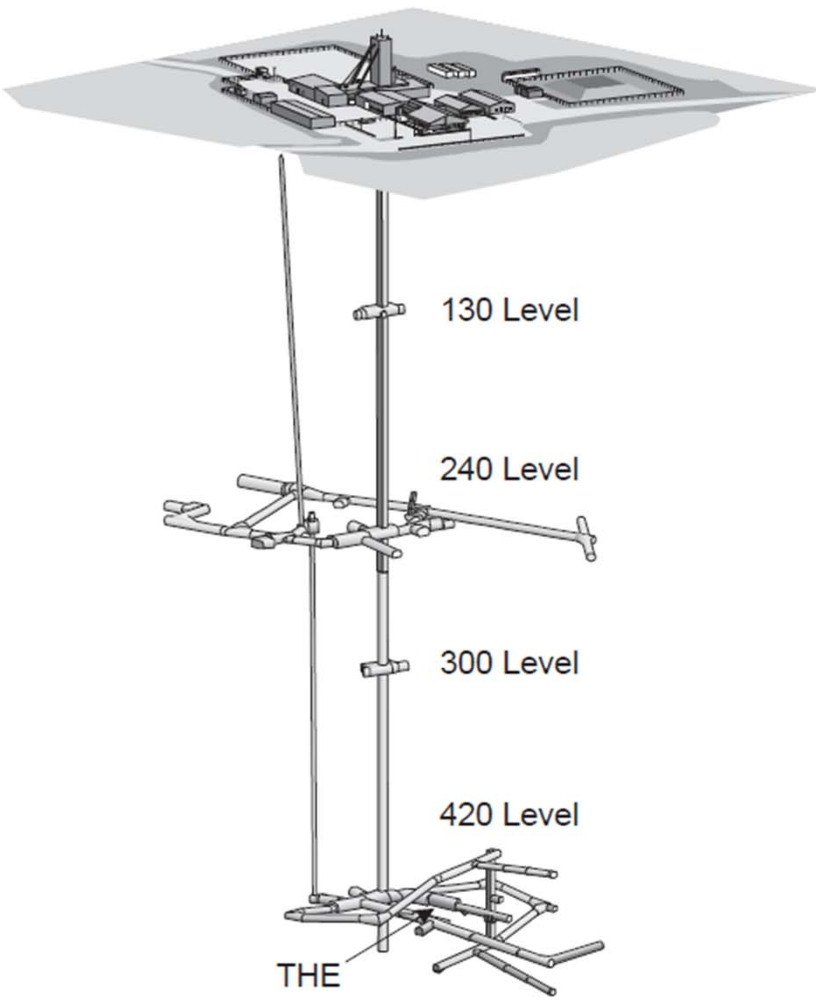
Fig. 2 - Eccentric Loading From Slanted Hole

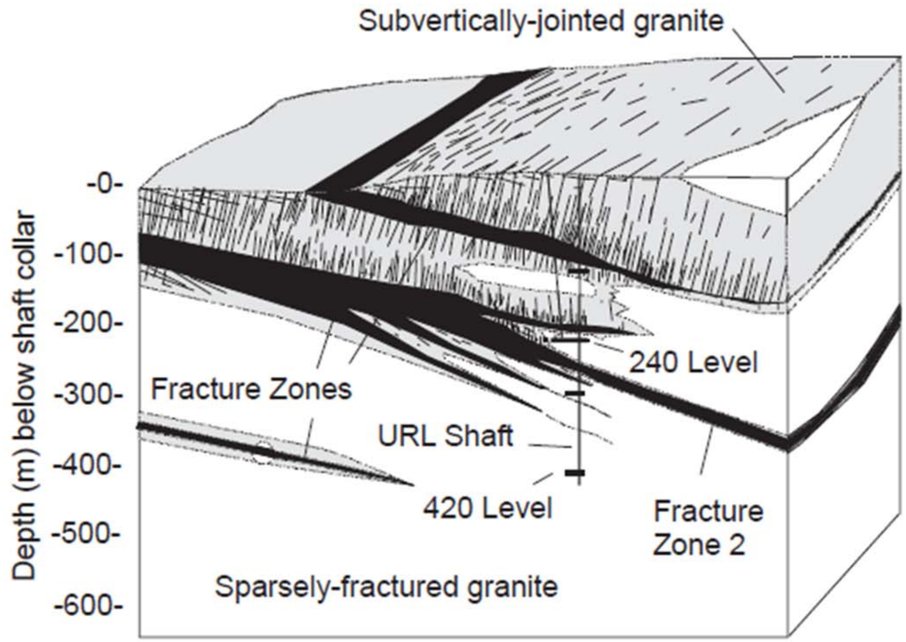
Muharaj 1996, SPE36143

Heating expands: Less-often recognized example

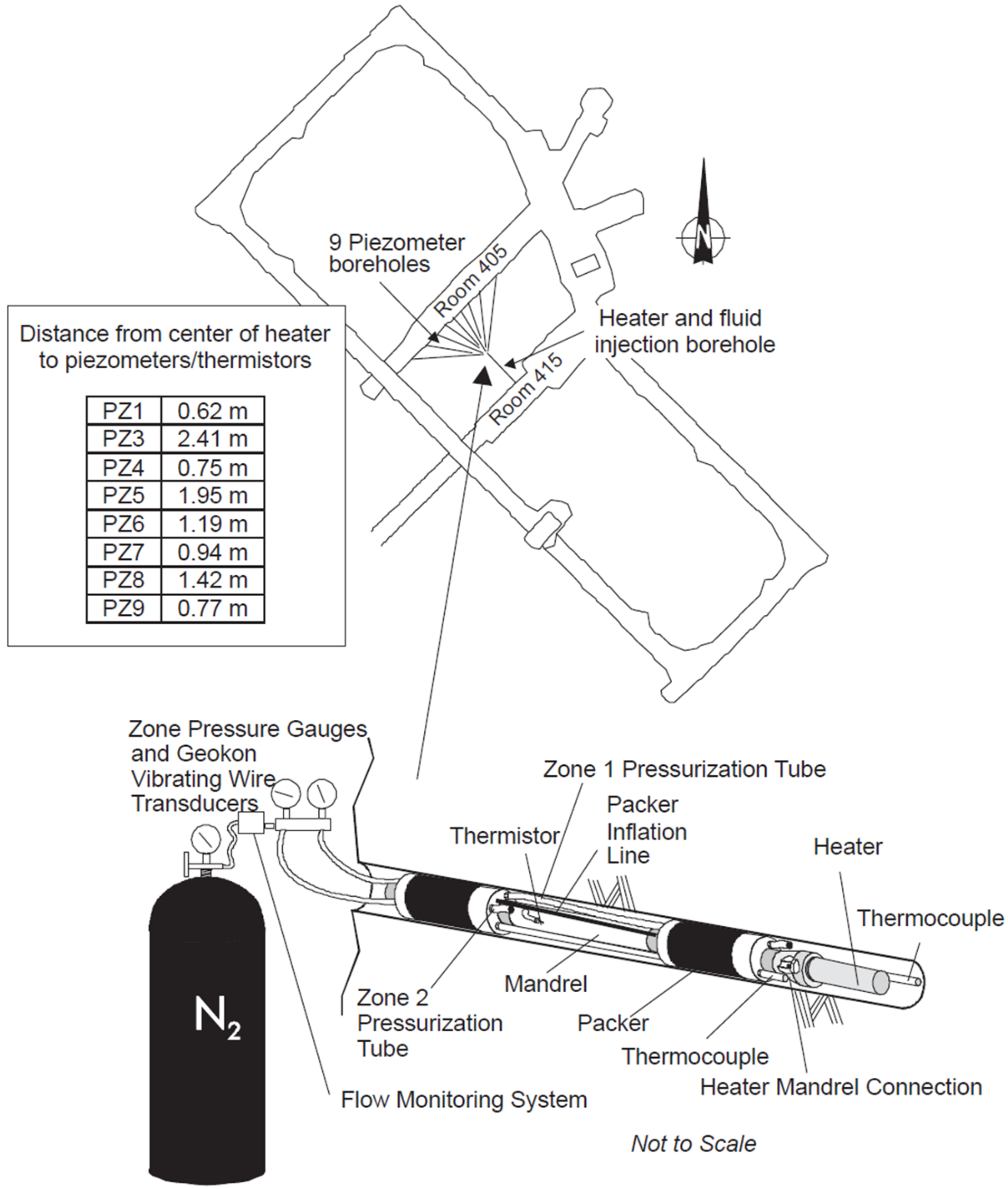
THE Experiment at Canadian URL

Berchenko, I., Detournay, E., Chandler, N., & Martino, J. (2004). An in-situ thermo-hydraulic experiment in a saturated granite I: design and results. International Journal of Rock Mechanics and Mining Sciences, 41(8), 1377-1394.





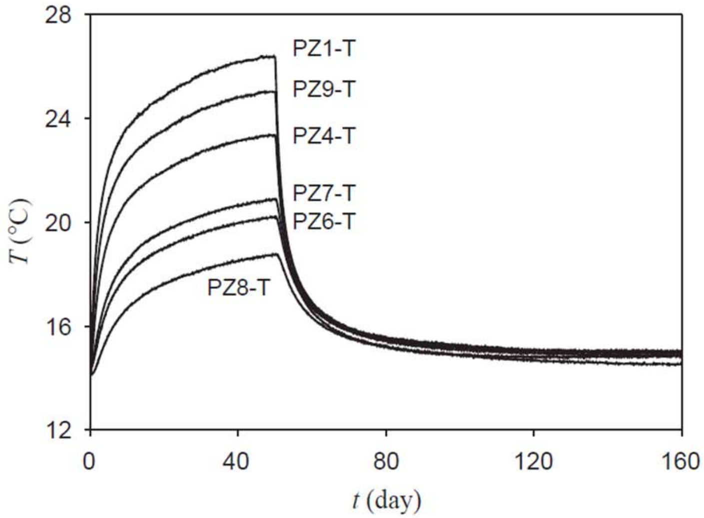
THE experiment at Canadian URL

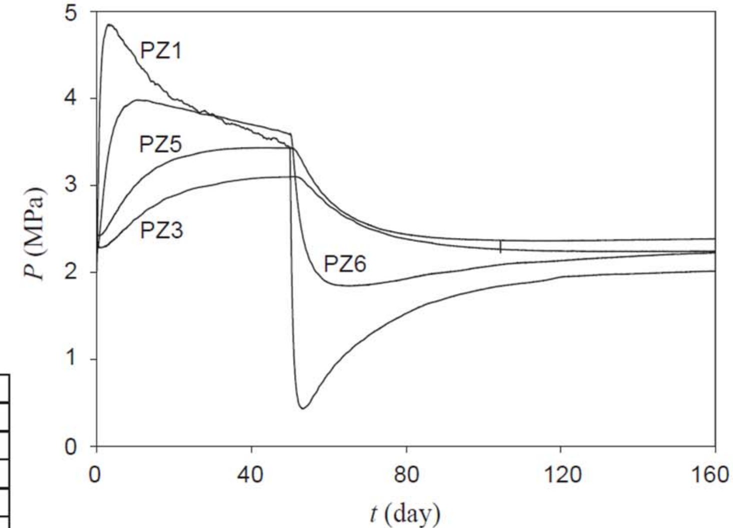


Distance from center of heater to piezometers/thermistors

PZ1	0.62 m
PZ3	2.41 m
PZ4	0.75 m
PZ5	1.95 m
PZ6	1.19 m
PZ7	0.94 m
PZ8	1.42 m
PZ9	0.77 m

THE experiment results





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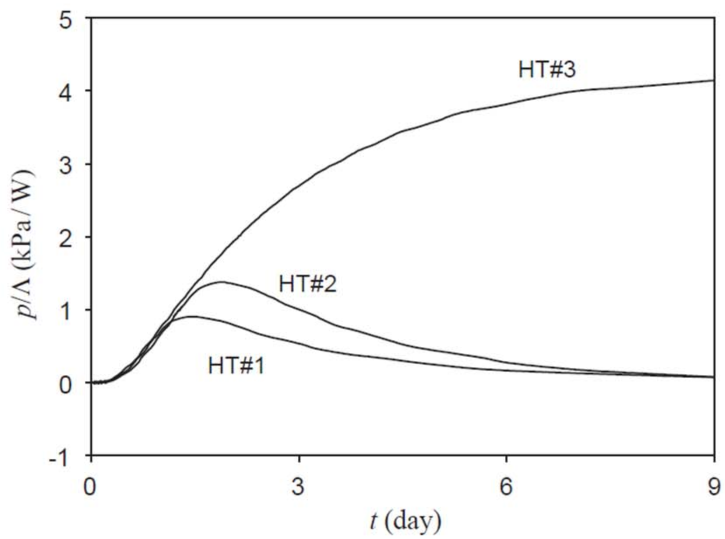


Fig. 16. Normalized pore pressure measured at PZ6 during the heater tests.

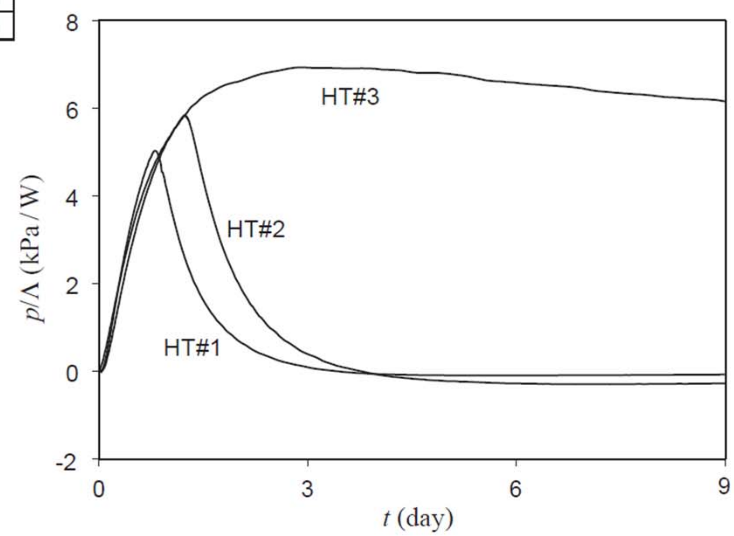
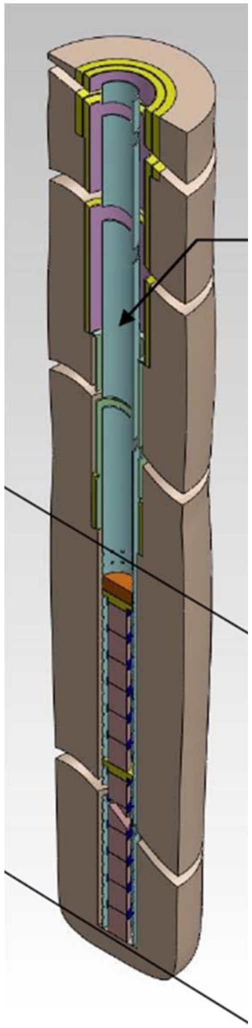


Fig. 15. Normalized pore pressure measured at PZ1 during the heater tests.

Because heating expands

- Completion materials/construction that does not result in failure upon subsequent heating, especially during construction
- Heating paths that do not result in pore-pressure-induced hydrofractures, especially in "cap rock"
  - Much more power than previous experiment
  - ...but distributed over much larger length



Thermo Hydro Mechanical (THM) modeling that is

- Informed by laboratory experiments
- Verified by field experiments

Other issues

- Intervention: Fixing a leak in a plugged well
- Monitoring
  - Where? What temperature?
  - Some topics:
    - Contaminant transport models to guide sensor placement
    - Sensors to withstand extreme temperatures

Baker Hughes, FracPoint

Research Priorities

- Drilling: Promoting a good quality hole
- Plugging
  - In presence of breakouts, induced and natural fractures
  - Chemical and mechanical behavior of clay-based plugging materials
    - During placement
    - In long term
- Casing and canister materials: Surviving well construction
- Thermo Hydro Mechanical issues: Preventing cap-rock damage
- Monitoring: Where, What, For how long?