# Shallow Borehole Disposal of Intermediate Level Nuclear Waste

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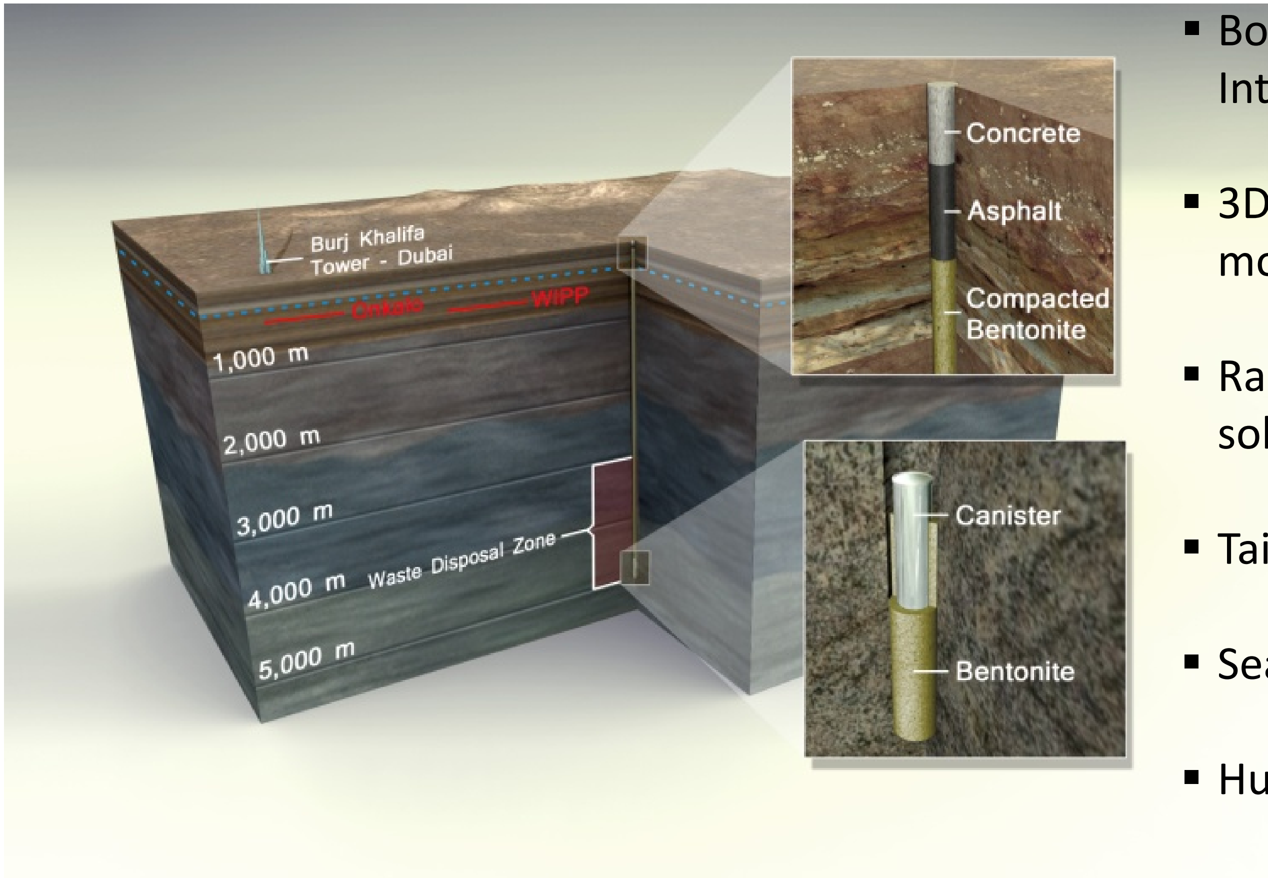


- Borehole Disposal: HLW vs. Intermediate
- 3D Thermal-hydrologic modeling
- Radionuclide solubilities/sorption
- Tailored backfills
- Seals
- Human Intrusion

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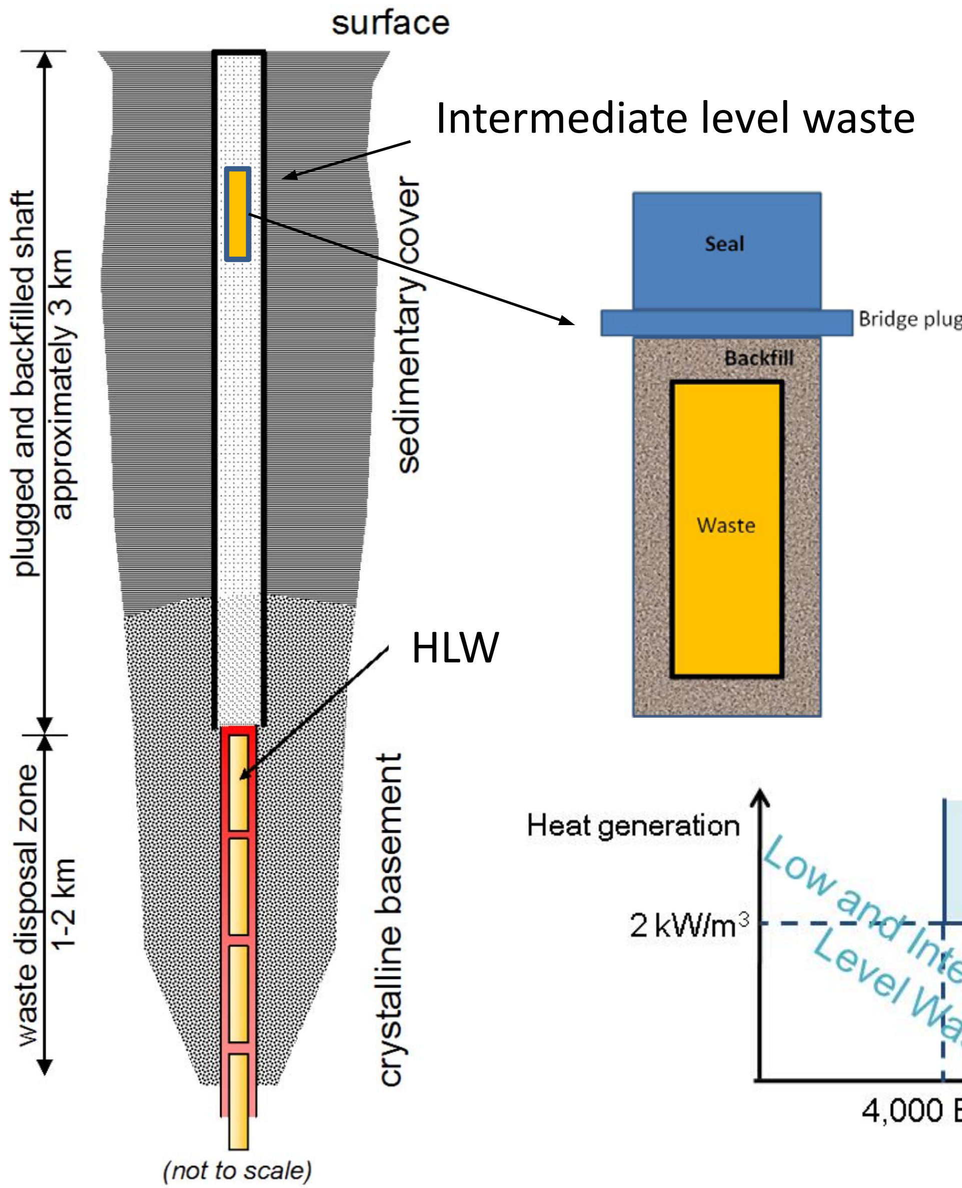
# Shallow Disposal of Intermediate Level Waste

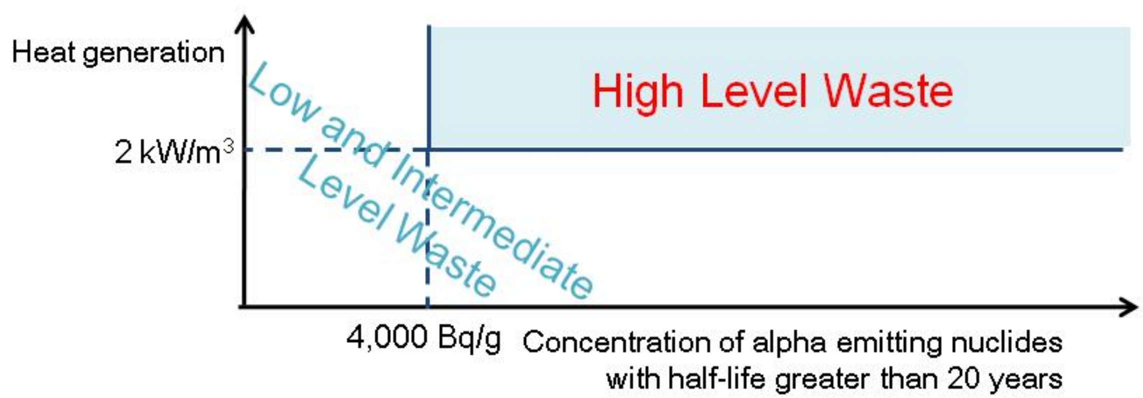



**Key Design Features**

10s to 100s meter depth
Metallic canister
Multiple seals
Tailored backfill

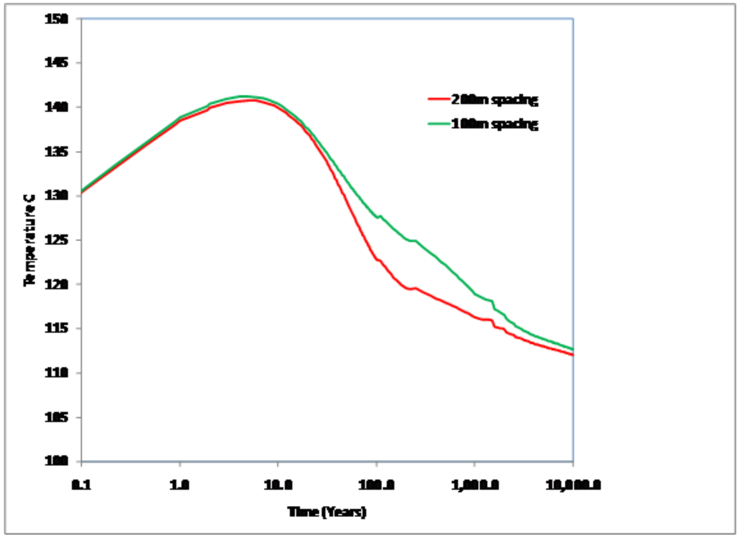
**Key Geochemical Features**

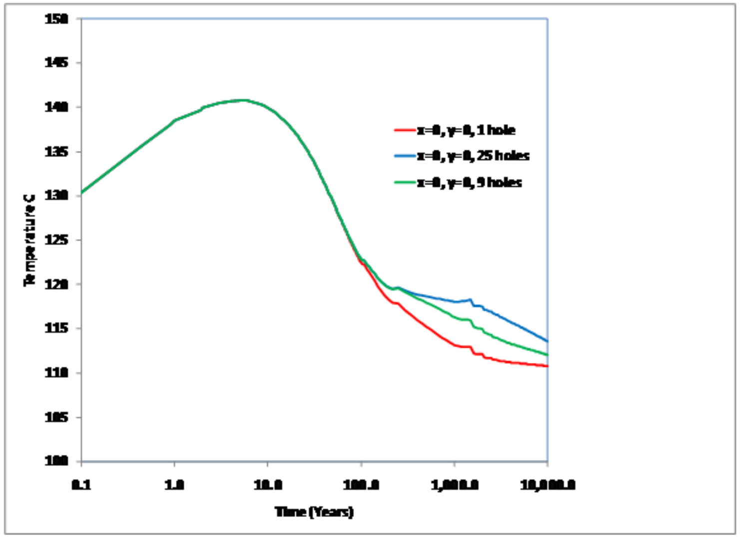
Reducing environment
Ample bicarbonate
Possible sulfate, sulfide



# 3D Thermal-Hydrologic Model: Multiple Boreholes

- Simulated peak temperature occurs relatively soon after waste emplacement and is insensitive to borehole spacing and number of boreholes
- Differences in temperature histories for multiple boreholes and closer borehole spacing are generally small
- Pressure and temperature conditions are below boiling for disposal of used fuel assemblies and high heat output vitrified waste from reprocessing
- Temperature perturbations are generally limited to the waste disposal zone (no significant vertical heat transport)



# Solubility and Sorption of Key Radionuclides

## Insoluble Radionuclides

| Element | Solid Phase | Concentration (mol/L) [a]Borehole | [b]Low $E_H$ Groundwater |
|---|---|---|---|
| Am | AmOCl | $2 \times 10^{-8}$ | $2 \times 10^{-9}$ to $10^{-5}$ |
| | $Am_2O_3$ | $3 \times 10^{-7}$ | |
| | $Am(OH)_3$ | $1 \times 10^{-5}$ | |
| Np | $Np(OH)_{4,am}$ | $1 \times 10^{-8}$ | $2 \times 10^{-12}$ to $10^{-8}$ |
| | $NpO_2$ | $2 \times 10^{-16}$ | |
| Pu | $Pu(OH)_{4,am}$ | $6 \times 10^{-6}$ | $10^{-11}$ to $10^{-6}$ |
| | $PuO_2$ | $2 \times 10^{-13}$ | |
| Tc | $TcO_2 \cdot nH_2O_{am}$ | $3 \times 10^{-8}$ | $10^{-12}$ to $10^{-7}$ |
| | [c]$TcO_2$ | $9 \times 10^{-13}$ | |
| | $Tc_3O_4$ | $2 \times 10^{-15}$ | |
| | Tc sulfides | $< 10^{-20}$ | |
| Th | $Th(OH)_{4,am}$ | $6 \times 10^{-8}$ | $10^{-10}$ to $10^{-9}$ |
| | $ThO_2$ | $4 \times 10^{-15}$ | |
| U | [d]$UO_{2,am}$ | $4 \times 10^{-4}$ | $10^{-10}$ to $10^{-6}$ |
| | $UO_2$ | $6 \times 10^{-9}$ | |

[a]Borehole solubilities calculated for 150°C, 1M NaCl, $C_{total}$ = 1 mM, $S_{total}$ =100 µmol, redox set by FeO-Magnetite equilibria. [b]From McKinley and Savage (1996). [c]25°C value from data0.ymp.r5d. All other thermodynamic values are from thermo.com.V8.R6.230. [d]ΔH set to -77.9 (Uraninite value).

## Soluble Radionuclides

| | Potential Solids |
|---|---|
| $^{14}C$ | $CaCO_3$ |
| $^{135,137}Cs$ | none |
| $^{129}I$ | (Metal iodides) |
| $^{226,228}Ra$ | (SS-$RaCO_3$, $RaSO_4$) |
| $^{90}Sr$ | (SS-$SrCO_3$, $SrSO_4$) |

long shots

## Sorption $k_d$s

| **Element** | **$k_{d\ basement}$** | **$k_{d\ sediment}$** | **$k_{d\ bentonite}$** |
|---|---|---|---|
| Am | 50-5000 | 100-100,000 | 300-29,400 |
| C | 0-6 | 0-2000 | 5 |
| Cs | 50-400 | 10-10,000 | 120-1000 |
| Np | 10-5000 | 10-1000 | 30-1000 |
| Pu | 10-5000 | 300-100,000 | 150-16,800 |
| [b]Ra | 4-30 | 5-3000 | 50-3000 |
| Sr | 4-30 | 5-3000 | 50-3000 |
| [c]Tc | 0-250 | 0-1000 | 0-250 |
| Th | 30-5000 | 800-60,000 | 63-23,500 |
| U | 4-5000 | 20-1700 | 90-1000 |
| I | 0-1 | 0-100 | 0-13 |

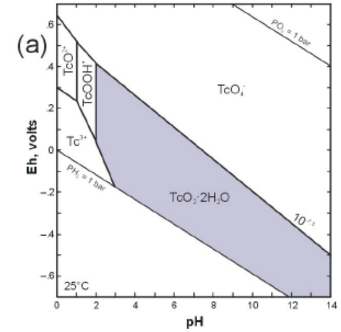
higher salinities will lower values

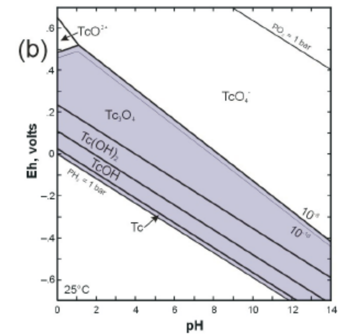
[a]All values are from the review of McKinley and Scholtis (1993). Values less than one were rounded down to zero. [b]$k_d$s for Ra were set equal to those of somewhat chemically similar Sr. [c]Tc $k_d$s under reducing borehole conditions will likely be much greater than the zero values listed here which were measured under more oxidizing conditions.

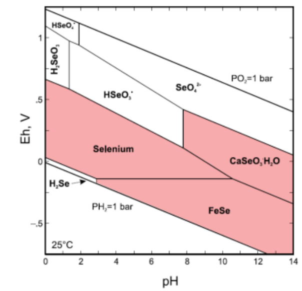
# Fate of Fission Products in Shallow Borehole Disposal

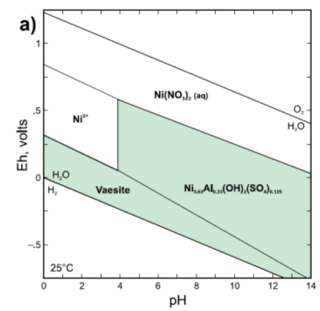
| Isotope | Chemical Control over Transport |
|---|---|
| $^{129}I$ | Sorption to Bi-doped bentonite |
| $^{14}C$ | Calcite formation |
| $^{36}Cl$ | Isotopic dilution |
| $^{59}Ni$ | Formation of Ni-Silicates, $NiCO_3$(?), $NiS_2$ |
| $^{3}H$ | * |
| $^{99}Tc$ | Formation of $TcO_2$, $TcS_2$ |
| $^{135,137}Cs$ | Inner layer exchange onto bentonite |
| $^{126}Sn$ | Formation of $SnO_2$ |
| $^{79}Se$ | Formation of $SeS_2$, FeSe |
| $^{107}Pd$ | Formation of PdO-$Pd(OH)_2$ |

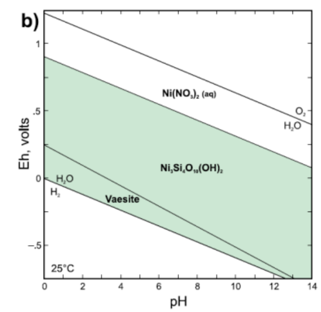
$E_H$-pH diagrams are from Vol. 2 and 3 of USEPA's Monitored Natural Attenuation Guidelines for Metals and Radionuclides (see http://www.epa.gov/nrmrl/pubs/600r10093/600r10093.pdf and http://www.epa.gov/nrmrl/pubs/600R07140/600R07140.pdf)

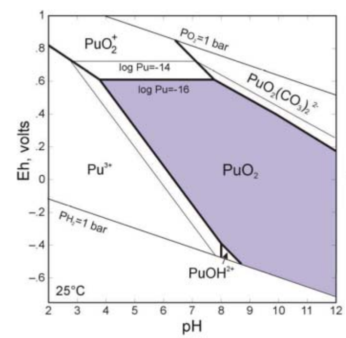


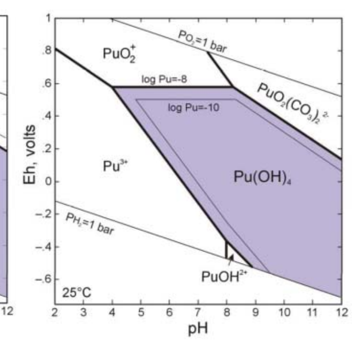



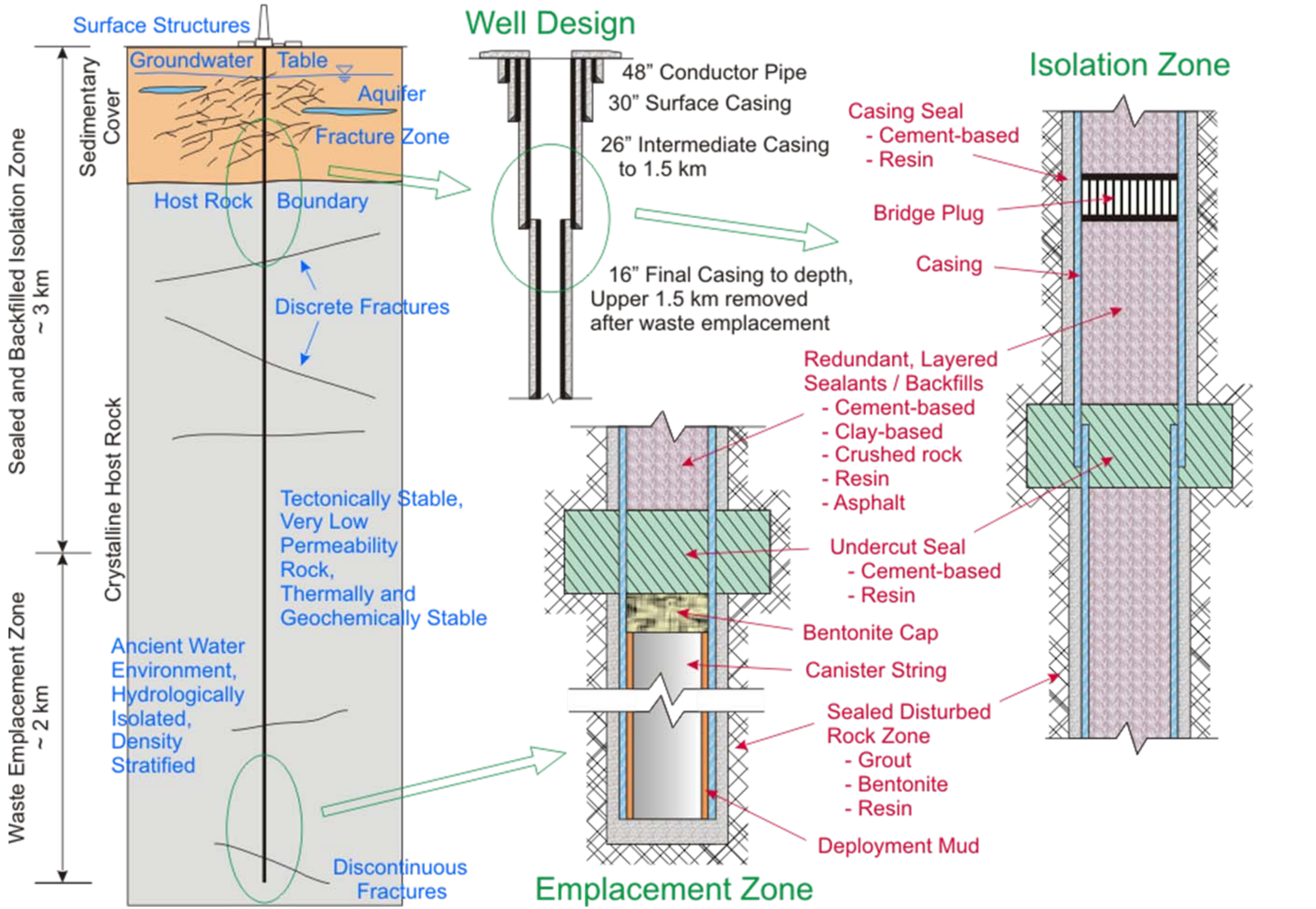



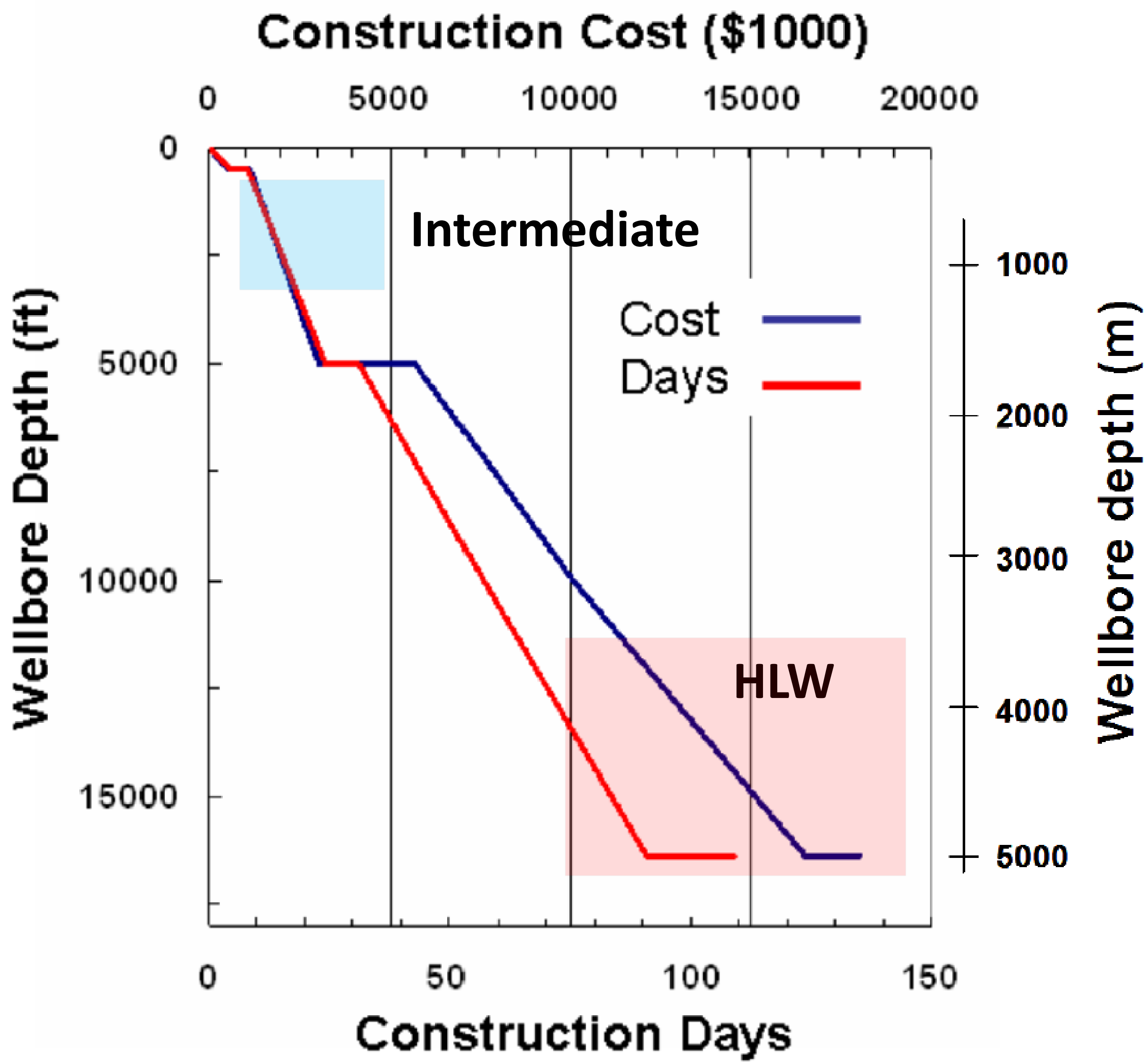



# Composite Borehole Sealing




Construction Cost ($1000)
0
5000
10000
15000
20000
Intermediate
Cost
Days
HLW
Wellbore Depth (ft)
0
5000
10000
15000
Wellbore depth (m)
1000
2000
3000
4000
5000
0
50
100
150
Construction Days