SAND2016-5241PE

Used Fuel Disposition Campaign

DREP Crystalline Repository Concepts – Review and Recommendations

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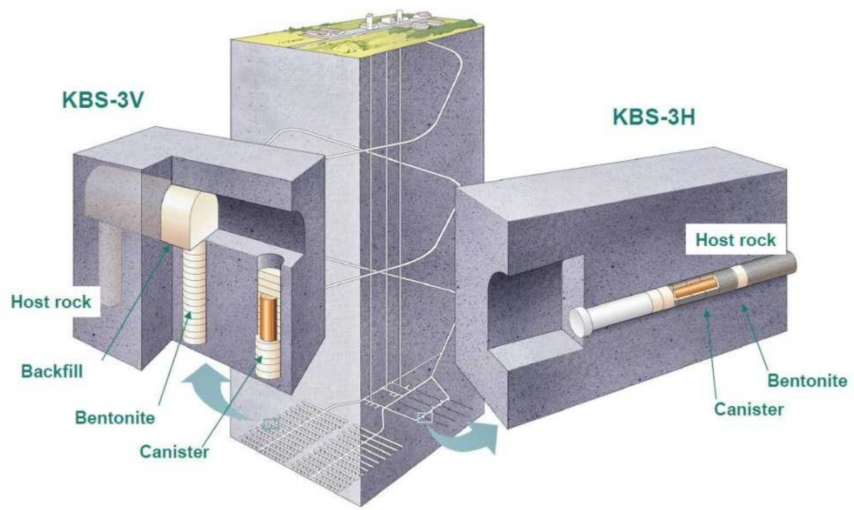
Disposal Concepts for a DRep in Crystalline Rock:
Identify Candidate Concepts for Evaluation

- **Objectives for Review: safety, cost, portability**
- **Disposal Concept ≡ WF + geologic setting + concept of ops.**
  - **Waste form:**
    - Mostly HLW glass, low heat output, SS pour canisters
    - DSNF of various types, pre-canistered, SS canisters
  - **Geologic setting:**
    - Competent rock (UCS > excavation stresses), thermally resistant (200°C), conductive faults/fractures, groundwater (or saltwater) saturated
    - Depth 500 m (boiling temp. >>200°C), shaft or ramp accessible
  - **Concept of operations?**

Disposal Concepts for a DRep in Crystalline Rock:
Defense Waste Characteristics

- **Low-thermal (up to 1 kW per 3- or 5-m canister)**
- **Long-lived radionuclides (~10^6-year assessment)**
- **Large numbers of canisters (from Carter et al. 2012)**
  - 3,542 DSNF (99.4% < 1 kW in 2030)
  - 23,032 HLW glass (SRS, Hanford & Idaho; all < 1 kW)
  - 3,600 Idaho calcine (24-inch dia. × 15 ft long; all << 1 kW)
- **Small canisters (mostly 18- and 24-inch diameters)**
  - Neglect Naval SNF which is most similar to CSNF
- **Relatively lightweight (canister + contents; no overpack)**
  - DSNF 5,000 to 10,000 lb
  - HLW 5,512 to 9,260 lb
  - Calcine ~6,000 to 7,000 lb (without HIP)
- **Material: stainless steel (welded, no heat treat, sensitized)**
- **All require some shielding**

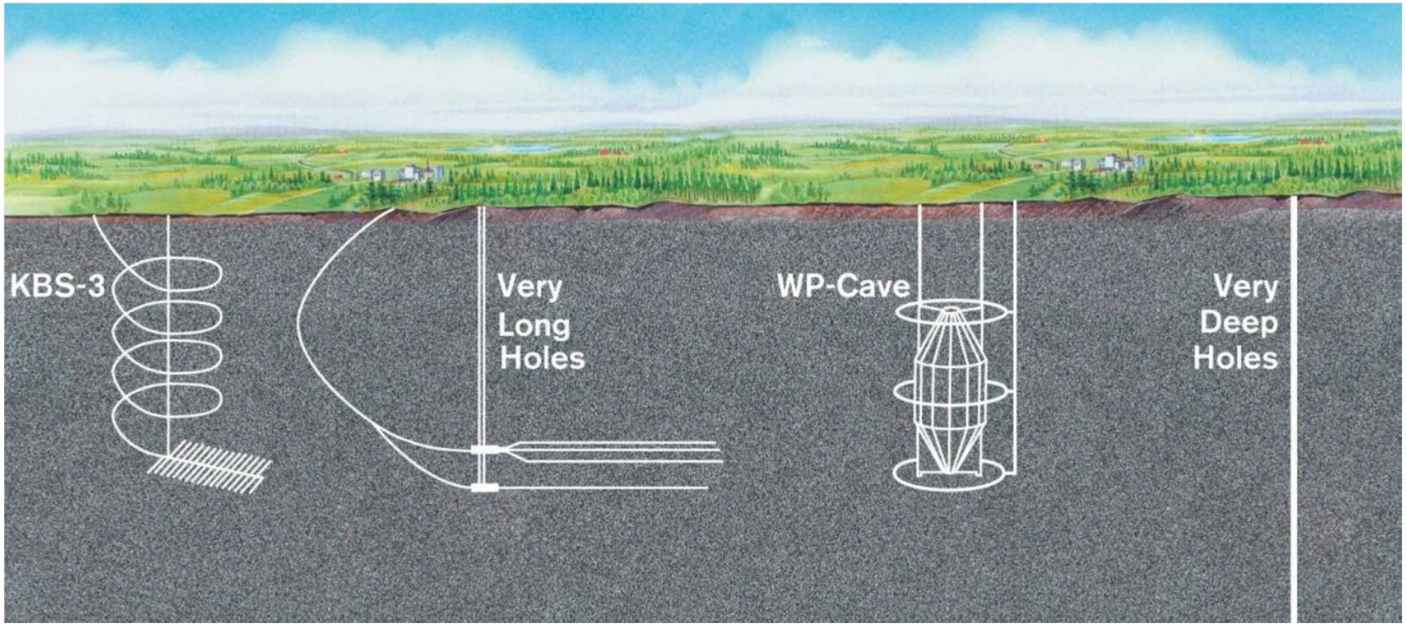
Disposal Concepts for a DRep in Crystalline Rock:
Crystalline Rock Geologic Settings



- **Competent Rock**
  - Only minor concrete/shotcrete
  - Large openings possible
  - Dimensional stability
- **Brackish/Briny Formation Fluid**
  - Salinity > seawater → ancient?
- **Fracture/Fault Permeability**
- **Hydraulic Gradients Present**
  - Even small head gradients (e.g., 10^{-4}) require low-k backfill
- **Waste Package Conveyance**
  - Shaft or ramp; supercontainer loads > 100 MT possible with ramp

Disposal Concepts for a DRep in Crystalline Rock: "Optioneering" KBS-3 (1/2)

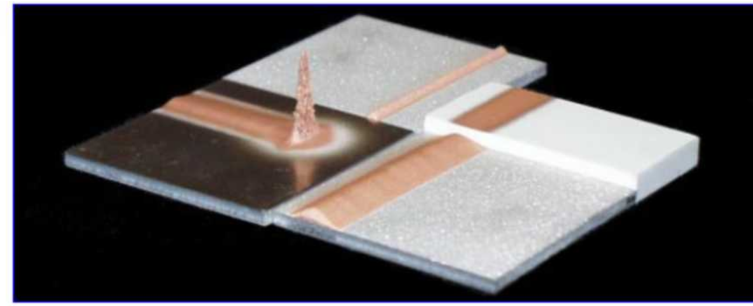
- **Emplacement mode**
  - KBS-3V vs. KBS-3H
  - WP-Cave and deep borehole
  - In-drift emplacement



Source:
SKB International Report 166: ***Spent Fuel Geologic Repository Consultation*****.** **Prepared for Savannah River Nuclear Solutions, LLC. Final Report, September, 2013.**

Disposal Concepts for a DRep in Crystalline Rock: "Optioneering" KBS-3 (2/2)

- **Canister**
  - Cu canister with a steel or cast iron insert
  - Cu canister made by hot isostatic pressing or cold-spray
  - E-beam, friction-stir welding
  - Steel, ceramic (Al2O3), or Ti-alloy canister
  - Coatings (amorphous metals, ceramic)
- **Buffer materials**
  - Clay, clay-sand, cementitious, "sandstone"
- **Supercontainers**



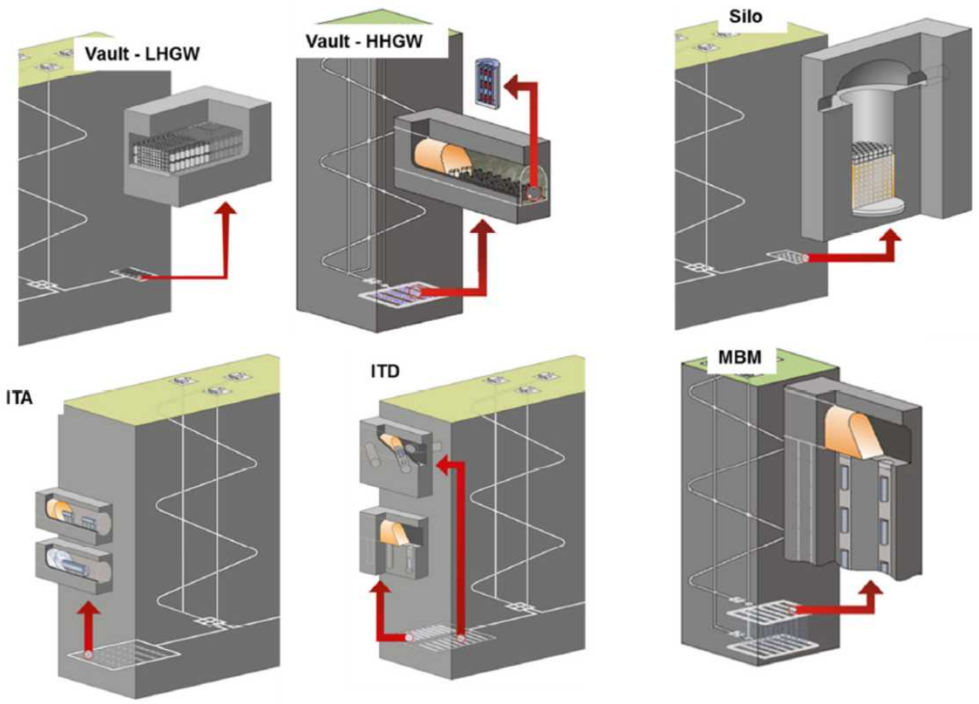
Examples of Materials Successfully Deposited at Sandia

Active Braze Alloy	Fe_3Pt	Polymer
Aluminum	Molybdenum	StelCar
Aluminum Bronze	Monel	Tantalum
Copper	80Ni/20Cr	Tin
304 Stainless Steel	NiCrAlY	Titanium
420 Stainless Steel	$NiCr\text{-}Cr_3C_2$	WC-Co (nanophase)

- **Construction methods**
  - TBM vs. drill and blast, shaft vs. ramp, buffer/backfill and closure options
- **Emplacement equipment**
  - Transporters, hoists, water/air bearings, tractor-pushers, shielding
- **Filler materials (molten lead, cement, glass beads)**
- **Rod consolidation**

Disposal Concepts for a DRep in Crystalline Rock:
KBS-3 + Other Crystalline Concepts

- **Pinawa (AECL, Canada)**
  - Ti or Cu packaging
  - Vertical-borehole emplacement
  - Buffer and backfill
  - Clay and/or cement-based
- **Mizunami (PNC, Japan)**
  - KBS-3H and KBS-3V reference
  - Concrete vaults
- **UK (RWM Ltd.) concepts >>>**
  - Vaults, in-drift and borehole
  - Pumpable buffer/backfill



Source: Watson, S. et al. 2014. *Disposal Concepts for Multi-Purpose Containers*. QRS-1567G-R7 Version 1. Radioactive Waste Management, Ltd., UK.

Disposal Concepts for a DRep in Crystalline Rock: NDA/EPRI Options Studies (1/5)

Table B-2
Key features and variants leading to the UNF and HLW disposal Concepts.

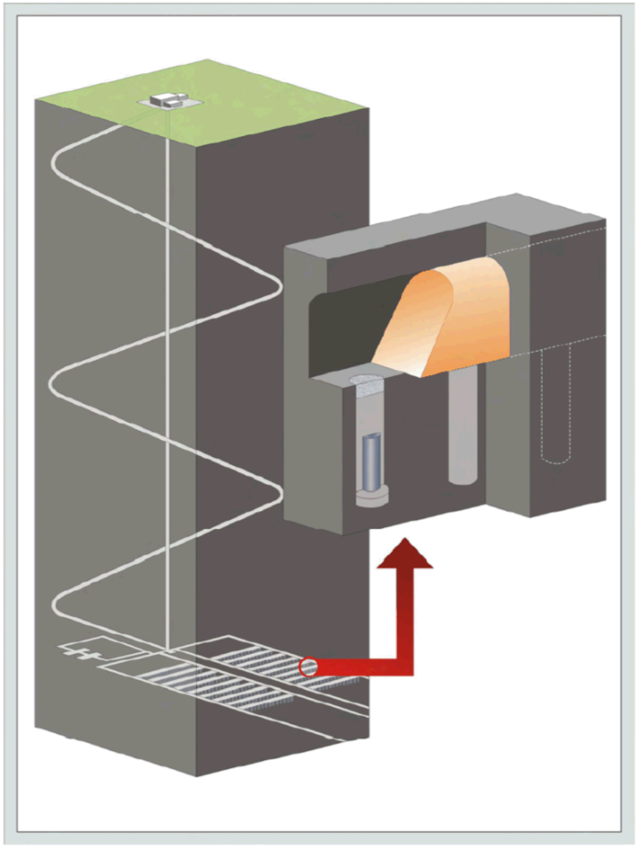
Key Feature	Variants	Concept No.
In-tunnel (borehole)	Vertical borehole	1
	Horizontal borehole	2
In-tunnel (axial)	Short-lived canister	3
	Long-lived canister	4
In-tunnel (axial) with supercontainer	Small working annulus	5
	Small annulus + concrete buffer	6
	Large working annulus	7
Caverns with cooling, delayed backfilling	Steel MPC + bentonite backfill	8
	Steel or concrete/DUCRETE container + cement backfill	9
Mined deep borehole matrix		10
Hydraulic cage	Around a cavern repository	11
Very deep boreholes		12

Sources for this and slides 9 - 13:

EPRI Review of Geologic Disposal for Used Fuel and High Level Radioactive Waste Volume III—Review of National Repository Programs. 1021614. December, 2010.

(After Baldwin, T., et al. 2008. *Geological Disposal Options for High-Level Waste and Spent Fuel*. Prepared for the UK Nuclear Decommissioning Authority, January, 2008.)

Disposal Concepts for a DRep in Crystalline Rock: NDA/EPRI Options Studies (2/5)

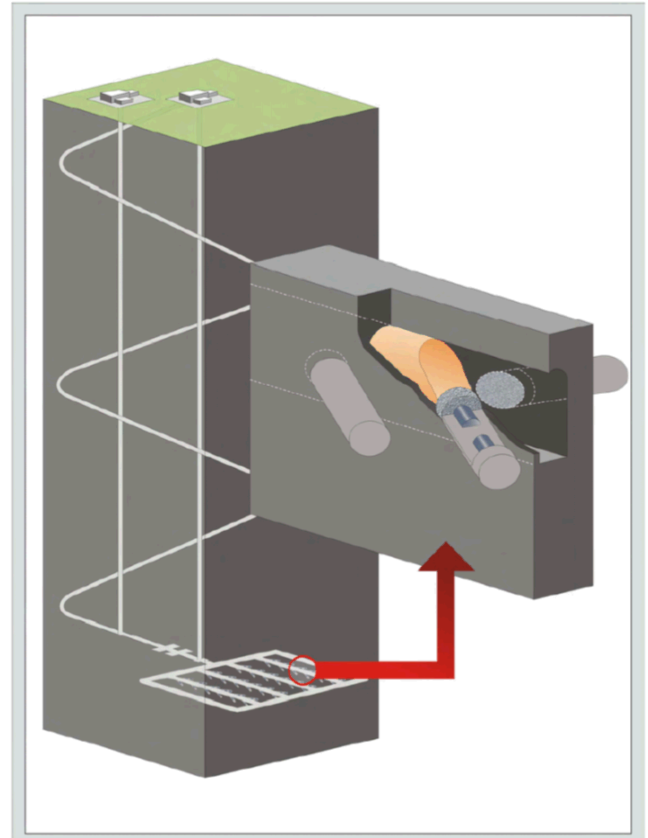


<<< #1

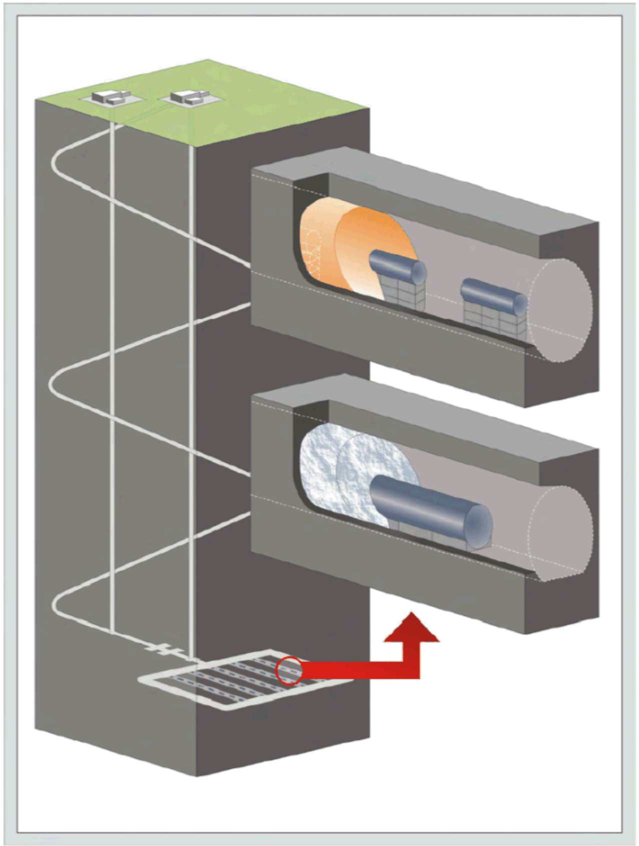
- Vertical borehole, outside DRZ
- Clay-based buffer & backfill
- Long-lived WP (Cu or Ti) for SNF IRF
- Short-lived for glass
- Mature for crystalline (KBS-3V)

#2 >>>

- Slant/horiz. holes
- Clay-based buffer and backfill
- Developed for clay
- Highly retrievable
- Low maturity



Disposal Concepts for a DRep in Crystalline Rock:
NDA/EPRI Options Studies (3/5)



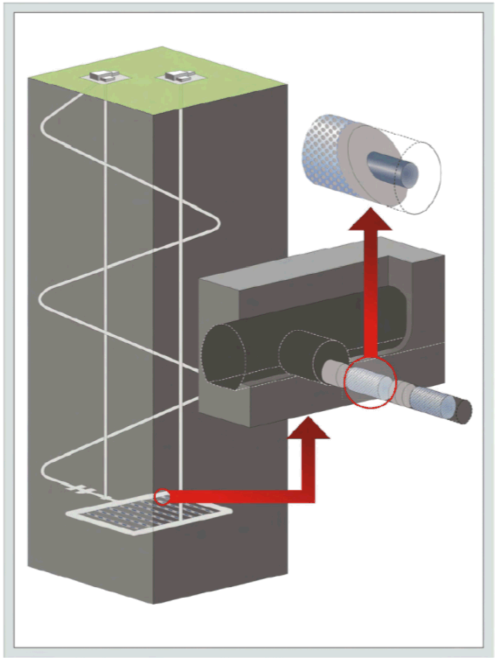
<<< #3

- In-drift axial
- Steel WP
- Thick clay-based buffer
- For relatively dry rock, limited DRZ
- Developed for clay
- Mature for clay, crystalline

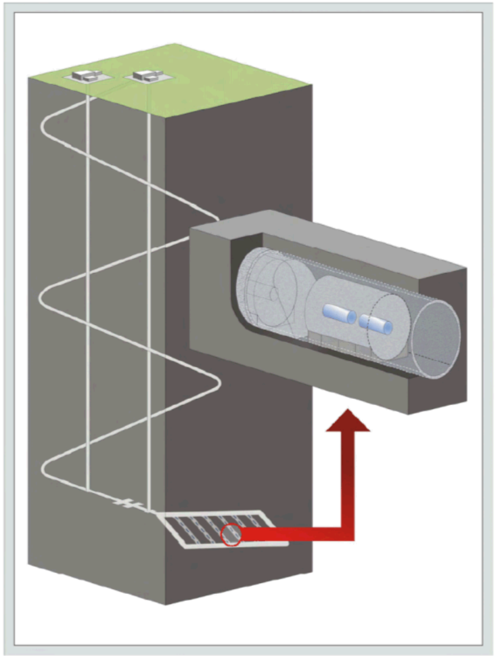
<<< #4

- Ontario Power concept (shown for salt)
- Corrosion resistant WP (Cu or Ti)
- Multi-part buffer/backfill
- Pre-fabricated compacted clay buffer
- Smaller packages may be side-by-side in pairs
- Adapt to highly stressed rock
- Mature for crystalline

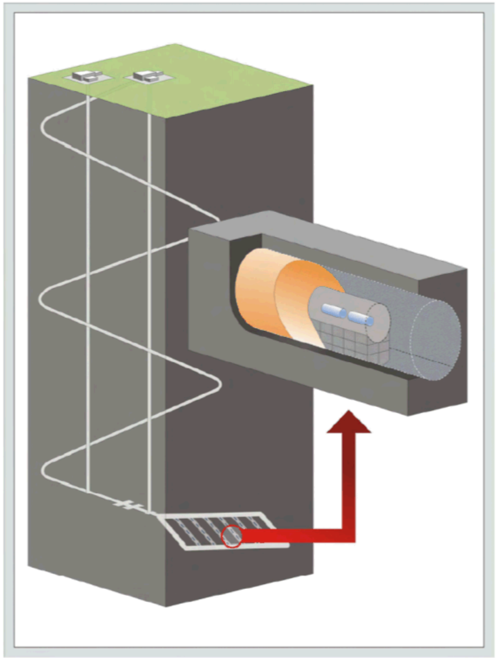
Disposal Concepts for a DRep in Crystalline Rock: NDA/EPRI Options Studies (4/5)



↑ #5
- Supercontainer, small annulus
- Corrosion resistant WP
- Inflow rate critical
- Mature for crystalline (KBS-3H)

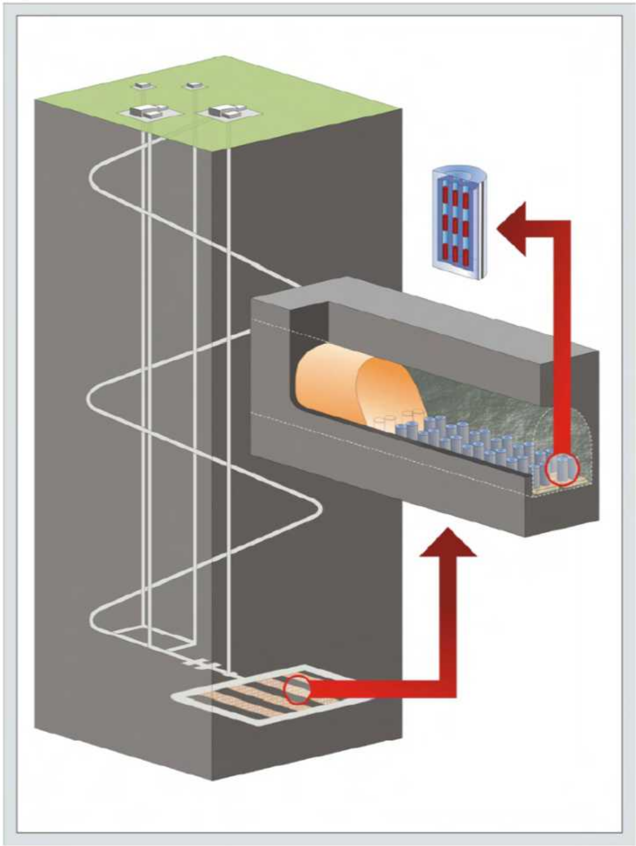


↑ #6
- Supercontainer with concrete buffer
- Long- or short-lived WP
- Mature for clay
- OPC interactions R&D



↑#7
- Supercontainer, large annulus
- Corrosion resistant WP
- Clay-based buffer and backfill
- Low maturity

Disposal Concepts for a DRep in Crystalline Rock: NDA/EPRI Options Studies (5/5)

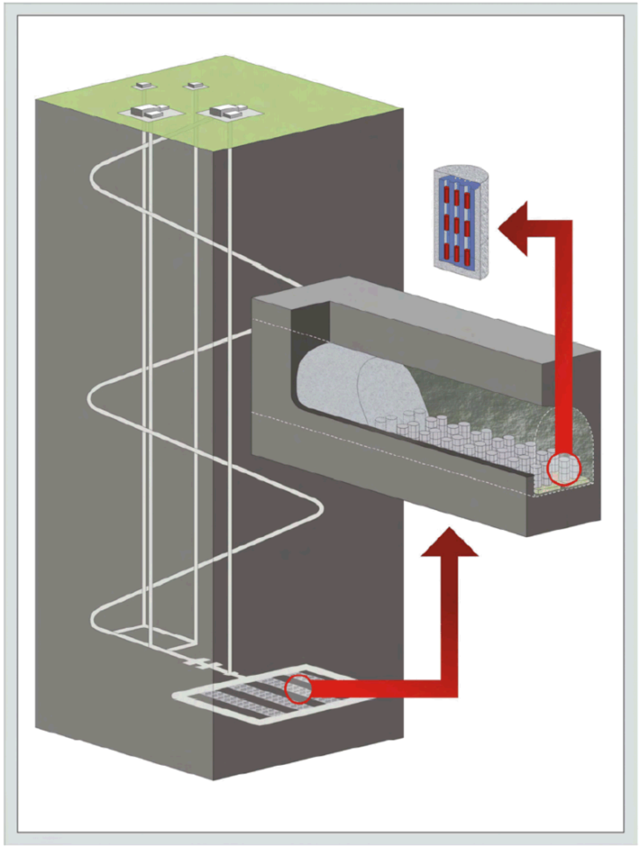


<<< #8

- Steel MPC, self-shielding
- Clay backfill
- Extended cooling
- Small footprint
- Highly retrievable (→300 yr)
- Backfilling method?
- Low maturity

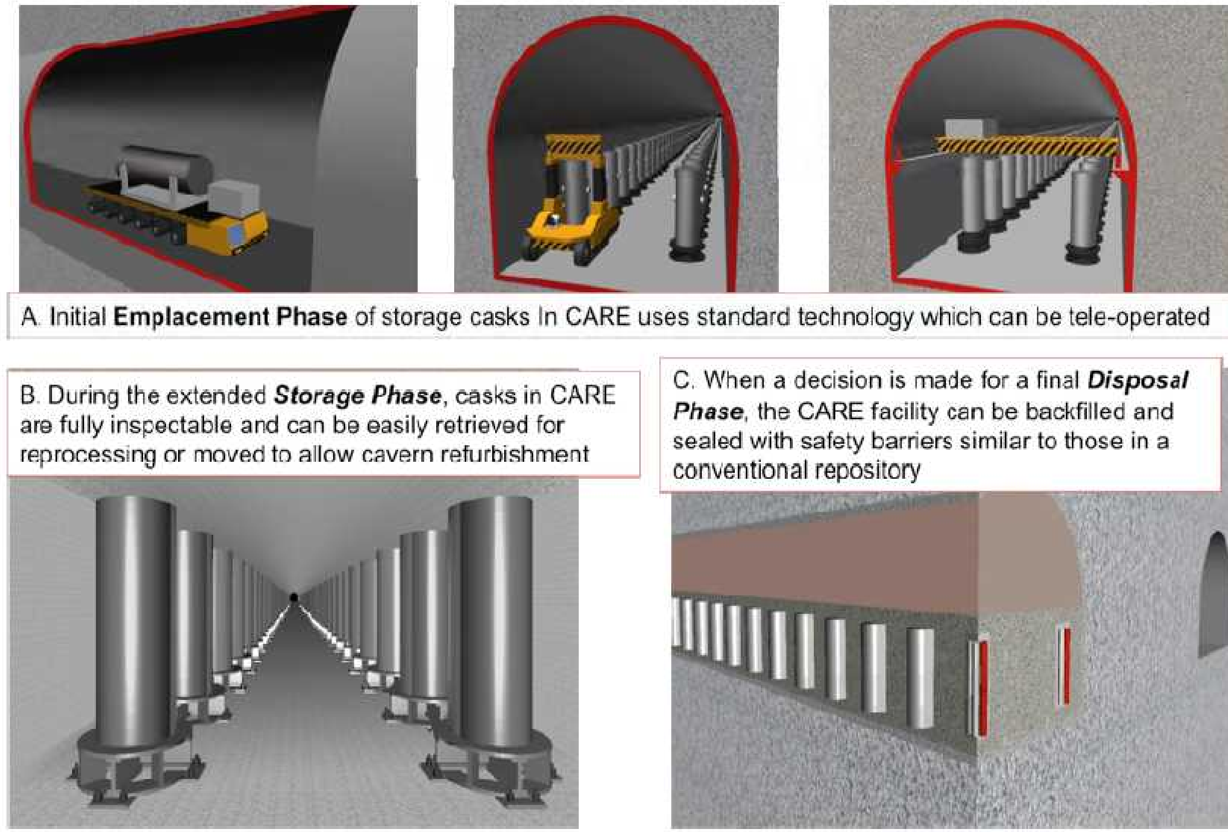
#9 >>>

- Steel MPC or concrete/DUCRETE casks, self-shielding
- Clay or cement backfill (pumpable?)
- Highly retrievable
- Low maturity



Disposal Concepts for a DRep in Crystalline Rock: Cavern-Retrievable (CARE) Concept

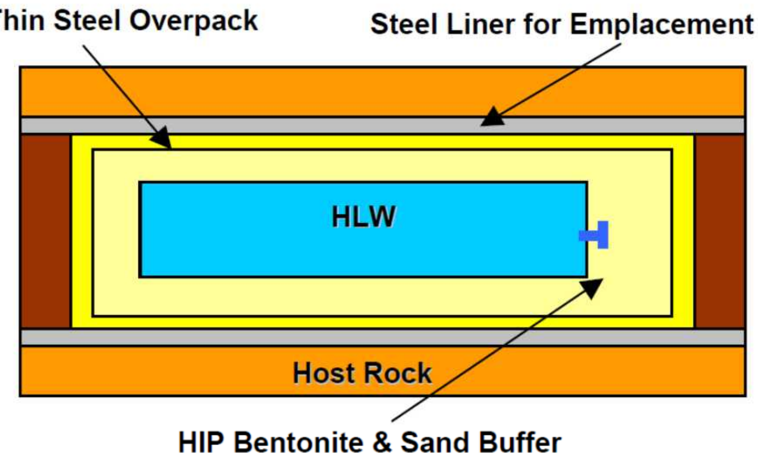
- After McKinley et al. (2008)
- Combine long-term retrievable storage
- Highly competent rock (relatively dry?)
- Self-shielded WPs
- Extended cooling
- Small footprint
- Highly retrievable (→300 yr)



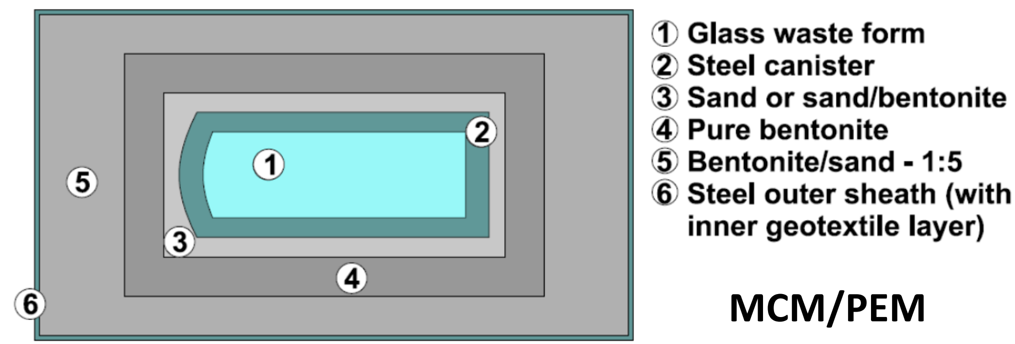
Used Fuel Disposition

Disposal Concepts for a DRep in Crystalline Rock: "2nd Generation" HLW Concepts (McKinley, et al.)

- **Integrated waste package (IWP)**
  - Pressed buffer in steel overpack
- **Multi-component module (MCM)**
  - Use of sand-clay mixtures inside and outside pure clay buffer
- **Prefabricated EBS Module (PEM)**
  - Up to 3 HLW canisters, bentonite, steel sheath
- **Sealants**
  - Inhibit inflow at the tunnel wall
- **Sandstone Buffers**
  - Flux diversion, package sinking, gas dispersion



IWP

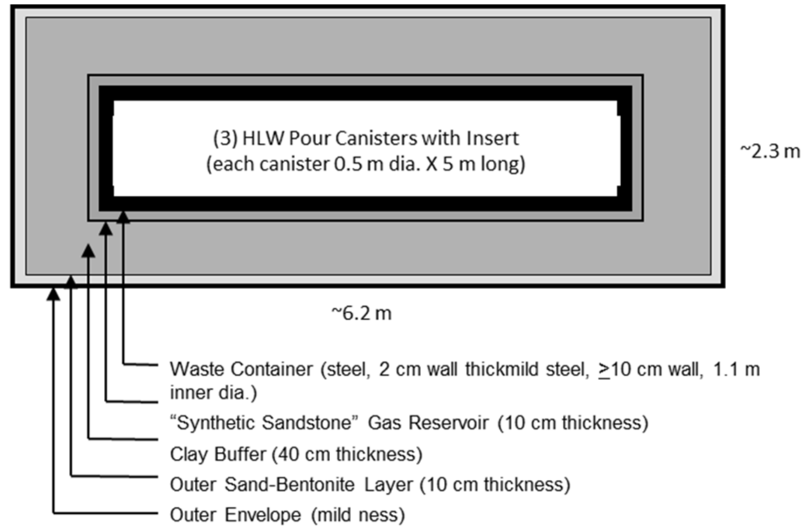


MCM/PEM

Source: McKinley et al. 2001. "Moving HLW-EBS Concepts into the 21st Century." Mat. Res. Soc. Symp. Proc. Vol. 663.

Disposal Concepts for a DRep in Crystalline Rock: What if the Host Rock is Unsaturated?

- **Natural smectite is a common secondary mineral in many settings, at oxidizing conditions**
- **Buffer erosion from higher flux, e.g., glacial onset/retreat**
- **Erosion insignificant (immeasurable) for pore flow velocities < 10^{-5} m/sec**
- **Piping could result from nonuniform initial saturation**
  - SR-Can excludes piping for inflow < 0.1 L/min per package
  - Equivalent to 500 mm/yr average flux (very unlikely for UZ settings)

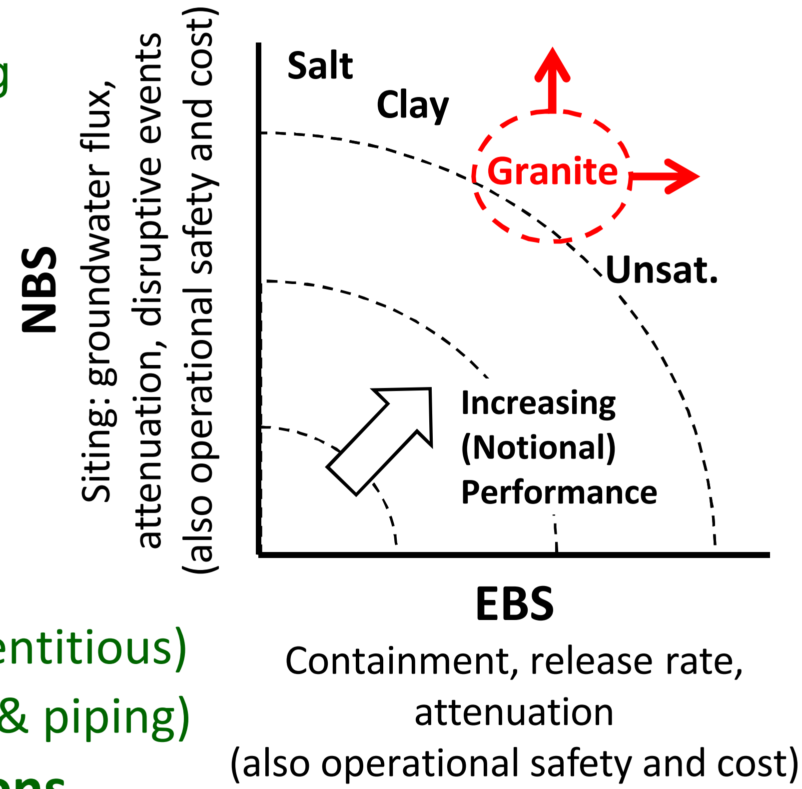


- **Total PEM weight ~90 MT depending on insert material**
- **Inserted into a vertical/horizontal mined/drilled opening**

Source: Hardin and Sassani 2011. "Application of the Prefabricated EBS Concept in Unsaturated, Oxidizing Host Media." International High-Level Radioactive Waste Management. SAND2011-2426C.

Disposal Concepts for a DRep in Crystalline Rock: So How Can We Improve on These EBS Concepts For Crystalline Rock?

- **Use D-Waste Characteristics**
  - Small, cool canisters & modest shielding
- **Simplicity & Technical Maturity**
  - Favorable (generic) site characteristics
  - Consider published approaches
- **Discriminate Final State from Engineering/Construction Methods**
- **Identify R&D Opportunities:**
  - Packaging materials (metals, coatings)
  - Buffer materials (clay, clay-sand & cementitious)
  - Pre-fabrication (buffer density, erosion & piping)
- **Cautiously Approach Cost Considerations**
  - Claim constructability and low cost; include engineering R&D cost
  - Correct attribution of GDSA performance



Disposal Concepts for a DRep in Crystalline Rock:
Crystalline DRep Recommendations

* Used in current GDSA models

- **Panel Layout by Waste Form***
- **Corrosion-Resistant Packaging***
  - Use existing HLW and DSNF canisters
  - Corrosion-resistant overpack performance
- **Low-Permeability Buffer and Backfill Materials***
  - Clay-based materials
- **In-Drift Emplacement (larger packages)***
  - Minimize tunnel volume, characterize inflow conditions
- **Borehole Emplacement (smaller DSNF packages)***
  - Short vertical or horizontal boreholes
- **Favorable Site Characteristics***

Disposal Concepts for a DRep in Crystalline Rock: Summary and Conclusions

- **Cooler Waste**
  - Clay-based backfill/buffer material
- **Corrosion-Resistant Packaging**
  - Cu/Ti/Hastelloy/coatings
- **Package Size and Emplacement Mode**
  - Waste segregated in panels, by type
- **Cost Considerations**
  - Multi-packs for HLW glass
- **International R&D Recognized**
  - KBS-3V (NDA/EPRI #1 or #2)
  - In-drift emplacement (scaled up KBS-3H; NDA/EPRI #5 or #7 with supercontainer)

Disposal Concepts for a DRep in Crystalline Rock:
R&D Opportunities

- **Waste Forms**
  - Design for instant release fraction?
- **Package Materials**
  - Corrosion allowance or resistant?
  - Fabrication methods & coatings
- **Buffer/Backfill**
  - Mass transport, piping/erosion
- **Super-Containers**
  - Pre-fabrication, self-shielding
- **Moving Heavy Packages**
  - Conveyances & running surfaces
  - Tight drift clearances, water/air bearings
- **Bulk Material Delivery**
  - Pellet delivery, pumpable materials