SALT REPOSITORY ENGINEERED BARRIER SYSTEM DESIGN AND TESTING

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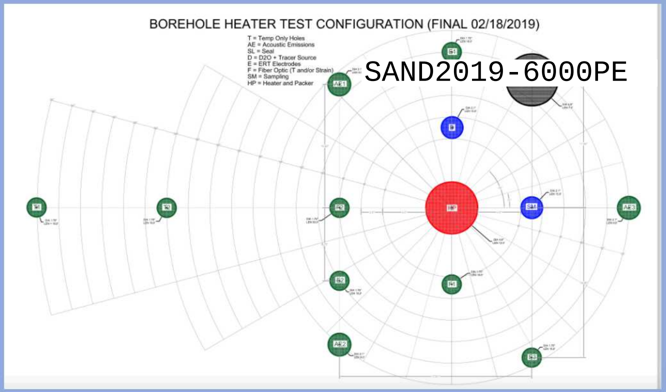
SAND2019-xxxx



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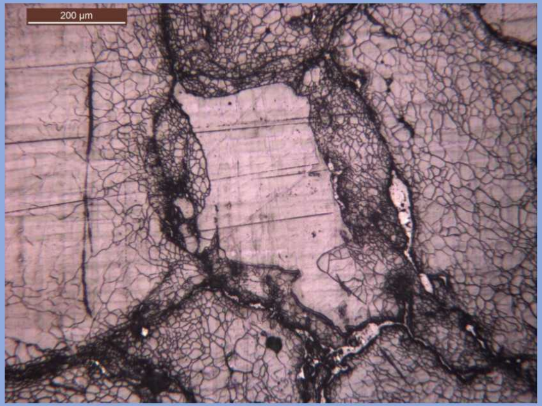

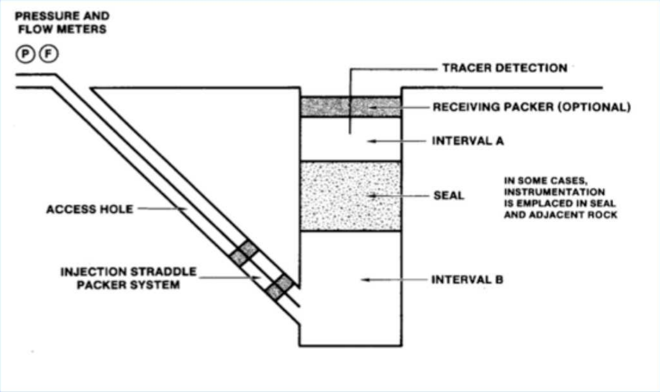

NEA SALT CLUB MTG.

Rapid City, SD USA
May 31, 2019

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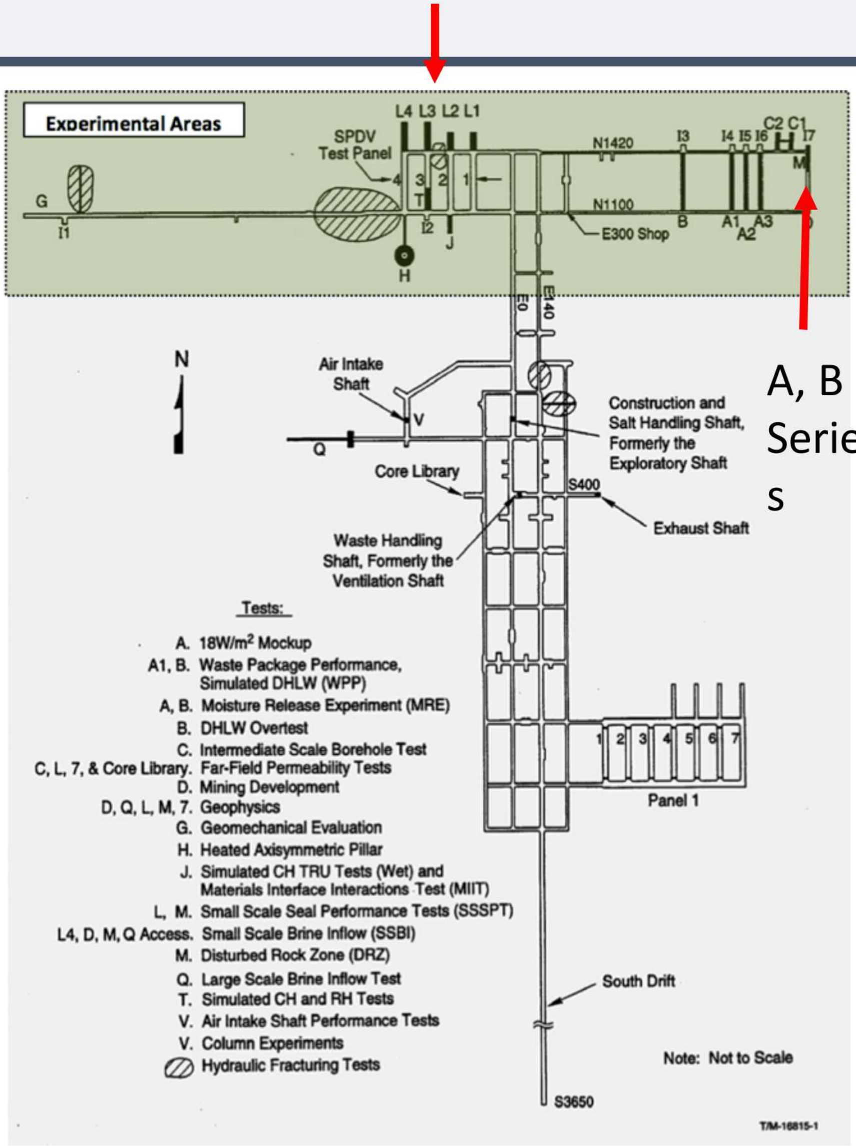
OVERVIEW

- Background of US Seal Tests in Salt
  - Small Scale Seal Performance Tests at WIPP
  - Challenges facing cementitious seals in salt
- Description of Seal Tests in BATS
- RANGERS and KOMPASS Collaborations with Germany

Small-Scale Seal Performance Tests (SSSPT)

- WIPP Experimental Area - Rooms L, M
- Vertical and horizontal boreholes
- Expansive Salt Concrete (ESC), Salt blocks, salt/bentonite blocks and backfill, ultrafine grout (F series)

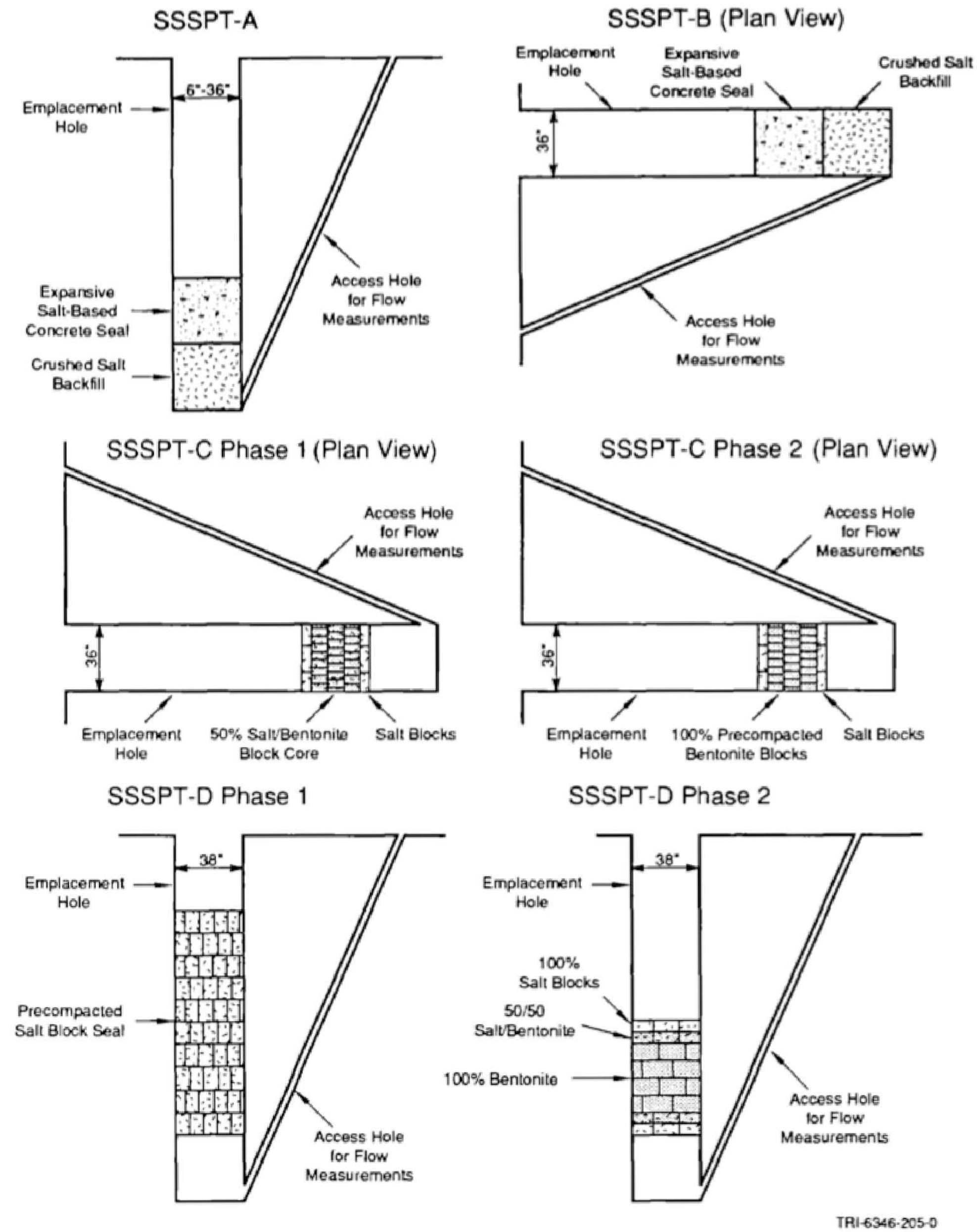


From Stormont 1987

SSSPT Configurations

TABLE 1. TEST SERIES CURRENTLY PLANNED FOR SSSPT				
Test Series	Seal Material	Seal Emplacement Orientation	Emplacement Date	Measurements*
A	Salt-Based Concrete	Vertical	7/85	Seal Pressure; Displacement and Temperature; Gas and Brine Flow
B	Salt-Based Concrete	Horizontal	2/86	Seal Pressure; Gas and Brine Flow
C Phase 1	Salt and 50/50% Salt/Bentonite Block	Horizontal	9/86	Seal Pressure; Brine Flow
C Phase 2	Bentonite Block	Horizontal	12/90	Seal Pressure; Brine flow
D Phase 1	Salt Block	Vertical	1/88	Seal Pressure; Hole Closure; Floor Heave; Gas Flow
D Phase 2	Bentonite Block (short-term)	Vertical	9/89	Seal Pressure; Brine Flow

* Note: Instruments include strain gages, stress meters, thermocouples, pressure cells, borehole displacement gages, Multiple Point Borehole Extensometers (MPBX), and the Four Packer Fracture Flow Tool (FPFFT) for fluid flow measurements.



From Finley et al. 1992

SSSPT Highlights, 1/2

- SSSPT Tests provide confidence to Performance Asessment in the form of *in situ* data on permeability and mechanical performance

Table III. Summary of SSSPT Seal System Permeabilities

Test Fluid	Concrete Permeability (m^2)	Concrete Permeability (m^2)	50%/50% Salt/bentonite Permeability (m^2)	100% Bentonite Permeability (m^2)
Test Period	**(1985-1987)**	**(1993-1995)**	**(1986-1990)**	**(1988-1995)**
Gas	$10^{-17} - 10^{-20}$	$10^{-19} - 10^{-23}$	–	see Figure 3
Brine	$\sim 10^{-19}$	$10^{-19} - 10^{-22}$	$\sim 10^{-16}$	$\sim 10^{-19}$

From Knowles and Howard 1995

SSSPT Highlights, 2/2

- Expansive Salt Concrete Seals
  - Exhibited sub-microdarcy permeability for both gas and brine (9 seals tested)
  - Flow path decreased within a year of emplacement (tracer test)
  - Emplaced using commercial equipment
  - AND optimized for key operational attributes including:
    - slump, limited bleed, segregation, limited air entrainment, self-leveling behavior, and workability
  - BUT…, in the late 80's the expansive agent became commercially unavailable (enter Salado Mass Concrete, next slide)
- Lessons learned with respect to cement formulations (from Wakeley 1987)
  - Simpler is better … for prediction, batching, sourcing, etc.
  - Working time is a critical property
  - By the late 80's, it became evident that **concrete** (not grout) would play a central role at WIPP as components in the sealing system for bulkheads and drift, panel, and shaft seals - as opposed to the primary seal
    - Lifetime requirements on the order of 100 years instead of 10,000 years

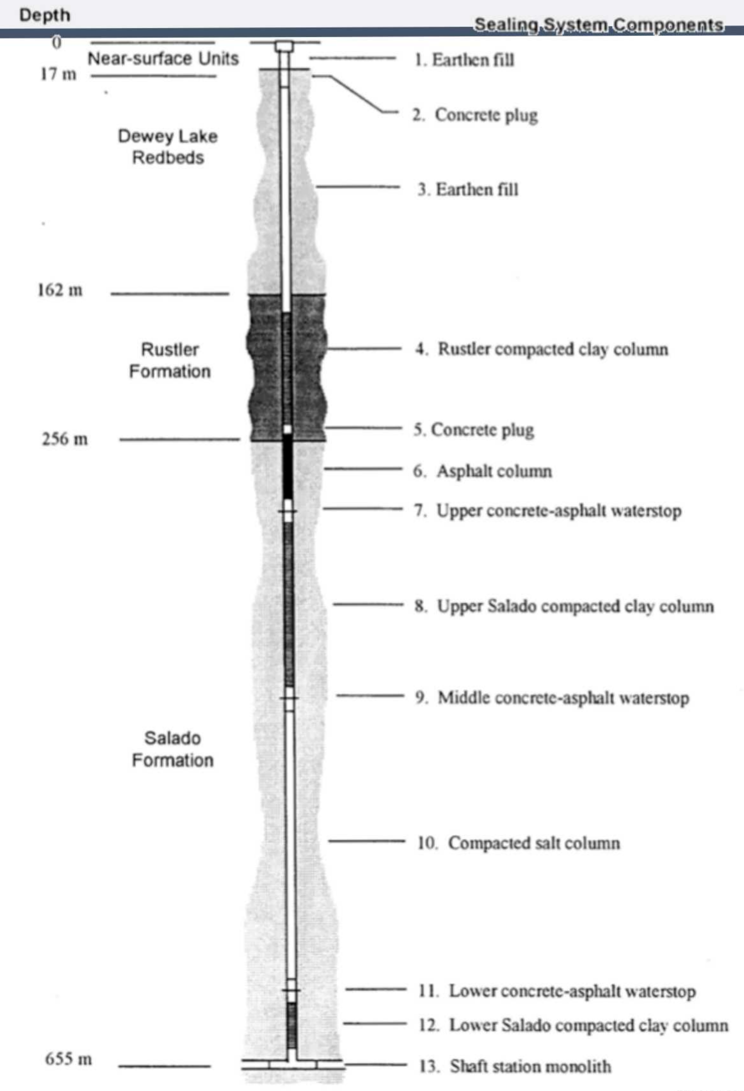
Salado Mass Concrete

- Incorporates the lessons from WES Grout Studies
- Dry batched at the surface, mixed underground
- As with previous grout/concrete studies, lab and field tests worked iteratively to meet targets for material properties

From Wakeley, Harrington, and Hansen 1995

DESIGN BASES, 1/2

- Seal performance standards (WIPP)
  - Concrete/grouts:
    - Have been proven/tested in the WIPP underground
    - Provide design redundancy as one element in a suite of seal materials in the overall seal design (**salt**, clay, asphalt)
- WIPP vs. DHLW
  - Increased radiologic source term
  - Thermal effects - cracking of seal materials
  - Chemical evolution in shaft and drift seals
    - Low pH cement?



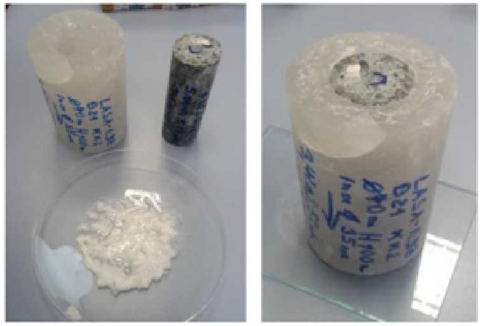
FROM HANSEN AND KNOWLES 1999

Cementitious Seals Test 1/2

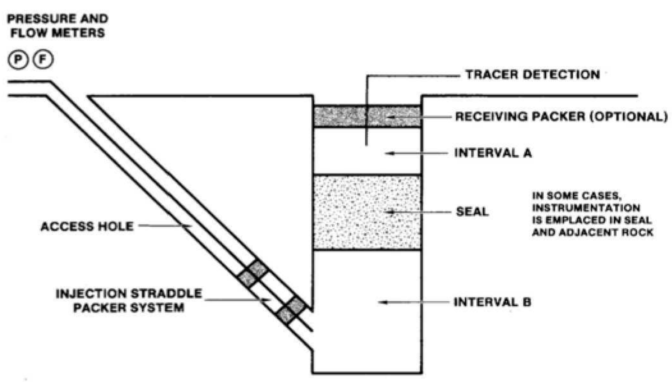
- Key issues for Cementitious Seal Performance Evaluation
  - Autogenous shrinkage of seal (during setting)
    - Gap formation at cement/salt interface
    - Crack formation in cement plug
  - Heat output of mass concretes
    - Crack formation in cement plug
  - Material selection (i.e., Sorel cement, salt concrete, low pH?)
  - Effects of salt host closure on the seal
- Why do a field-scale test of seals in bedded salt
  - Most recent field tests have been in domal salt (saltcrete, Sorel)
  - Bedded salt tests at WIPP - Small Scale Seal Performance Tests Series A, B, C
    - Used a very specific formulation of "Expansive Salt Concrete"
    - Key ingredients are unavailable and potential difficult to reproduce

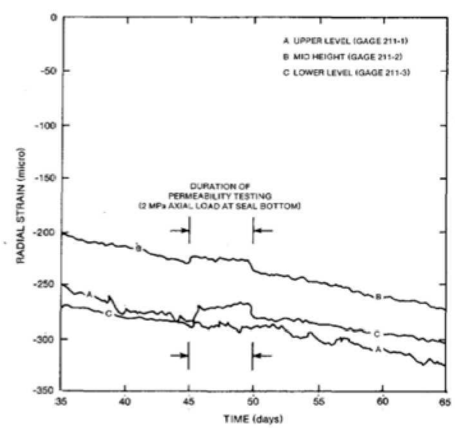
Cementitious Seals Test 2/2

- Relevant Tests in Domal Salt
  - Lab-scale Tests for DOPAS (Czaikowski et al. 2016)
  - ERAM Test Seal - salt concrete
  - Asse tests - Sorel cement and salt concrete
- Create a seal test at WIPP with the concept of a potential HLW Salt Repository in mind (with relevance to some generic, bedded salt site)
  - Measure borehole closure and permeability of the seal



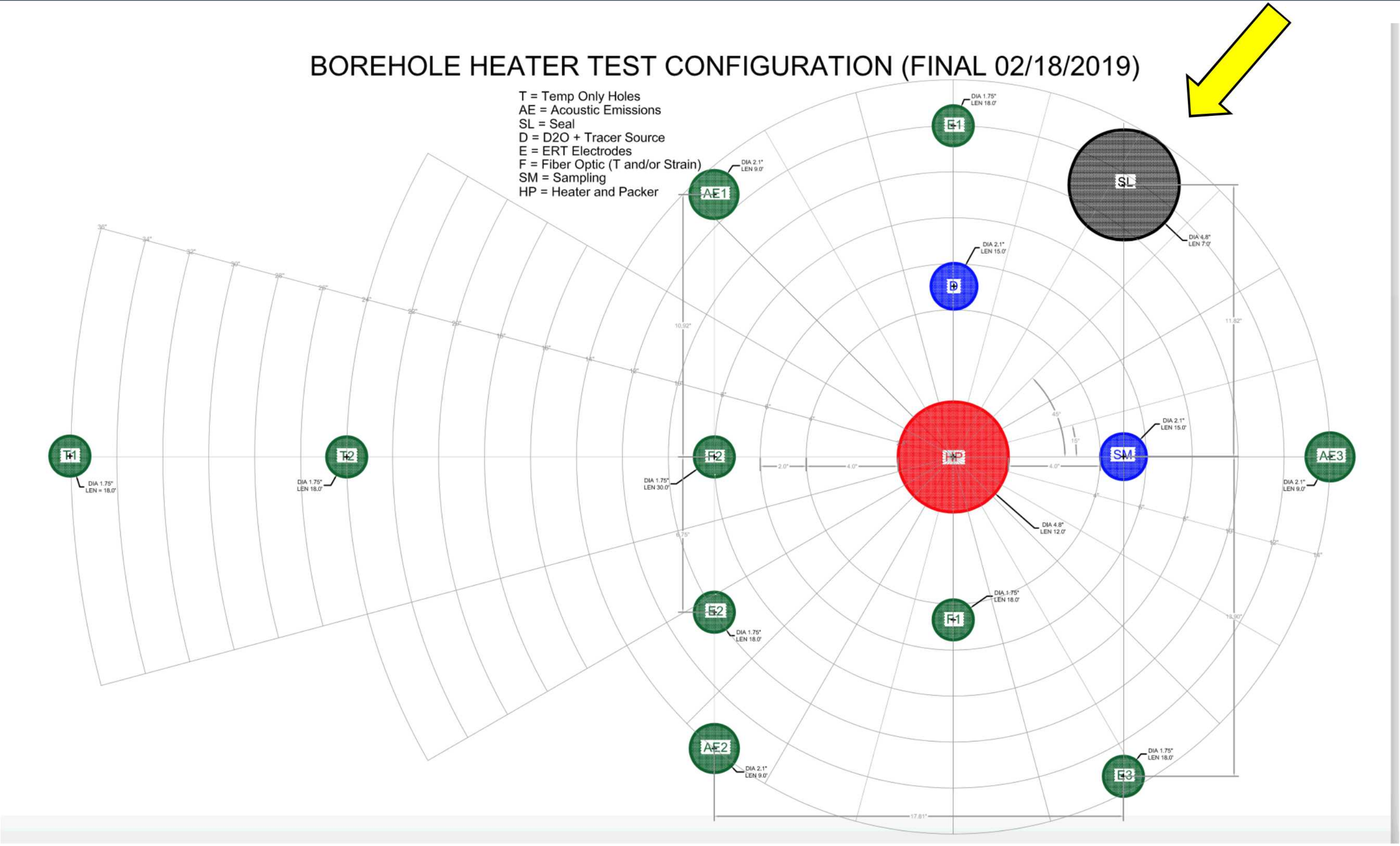
From Czaikowski et al. 2016





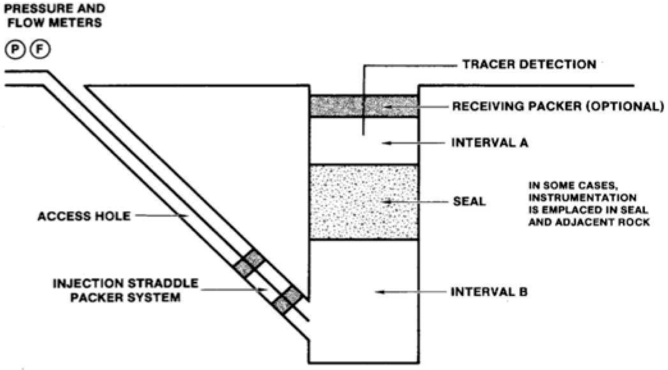
From Stormont 1987

BATS Borehole Layout, SL = Seal Borehole



Preliminary Seal Test in BATS

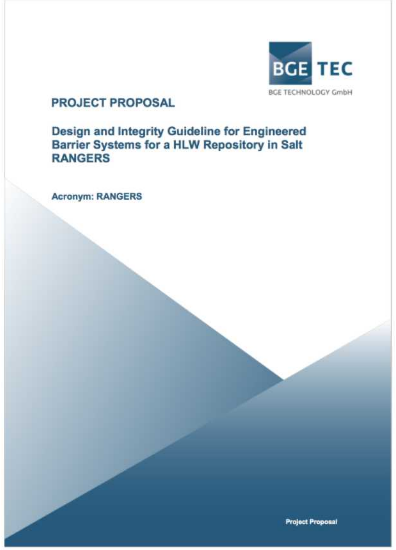
- Seal materials to test
  - Salt concrete
  - Sorel cement
  - OPC?
- Embedded strain gauges
- Thermocouples
- Post-test overcore and characterization
- Ultimately, would also eant to measure seal permeability *in situ*, as done in SSSPT



International Collaborations

RANGERS

- Compilation of existing knowledge and experience for the design and construction of geotechnical barriers and compilation of new concepts and technologies on the subject of geotechnical barriers.
- Development of a guideline based on the state of the art in science and technology for the design and verification of geotechnical barriers.
- Preliminary design and verification of the geotechnical barrier system for selected repository systems based on the developed guideline.
- Comparison of design results according to the new guideline with results of previous design and assessment.

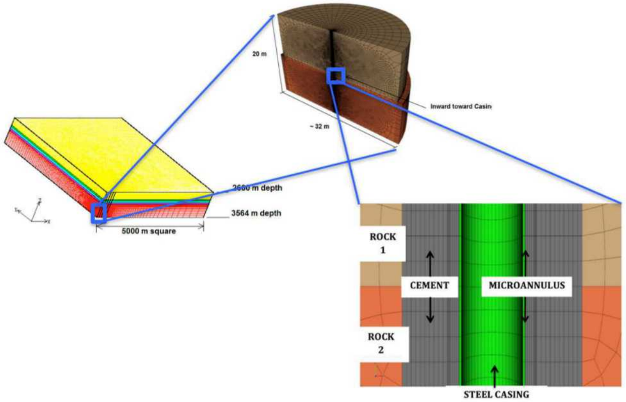

BGE TEC
BGE TECHNOLOGY GmbH

PROJECT PROPOSAL

Design and Integrity Guideline for Engineered Barrier Systems for a HLW Repository in Salt
RANGERS

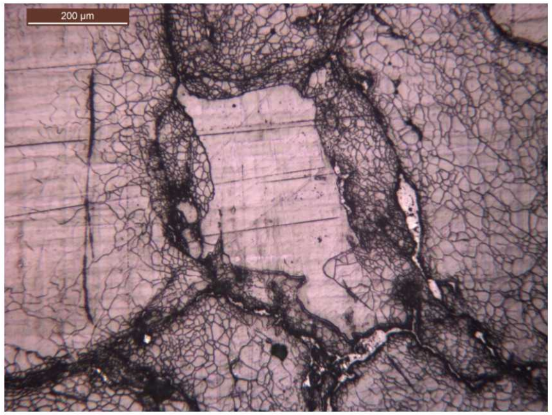
Acronym: RANGERS

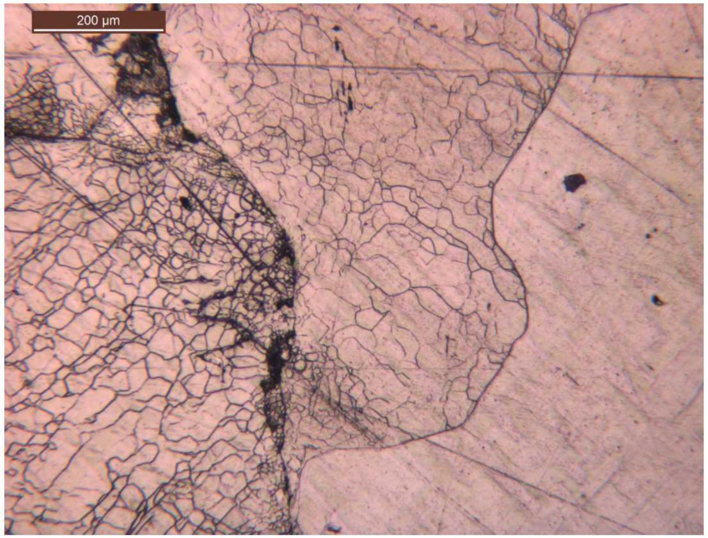
Project Proposal



KOMPASS

- Crushed salt behavior from long-term safety analysis perspective – why it has become so important; GRS
- Representative pre-compacted samples – possibilities, methods, new techniques; IfG & TUC,
- **Micro-structure investigations – key element to show long-term behavior; BGR & SNL (Melissa Mills)**
- Realistic modelling – generic and/or specific; BGE-TEC, BGR, GRS, IfG, TUC, **SNL (Reedlunn/Bean -Callahan Model)**





Questions?

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