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Potential Use of Geologic Rock Salt for Fuel Cycle Sustainability – a Computational Modeling Perspective

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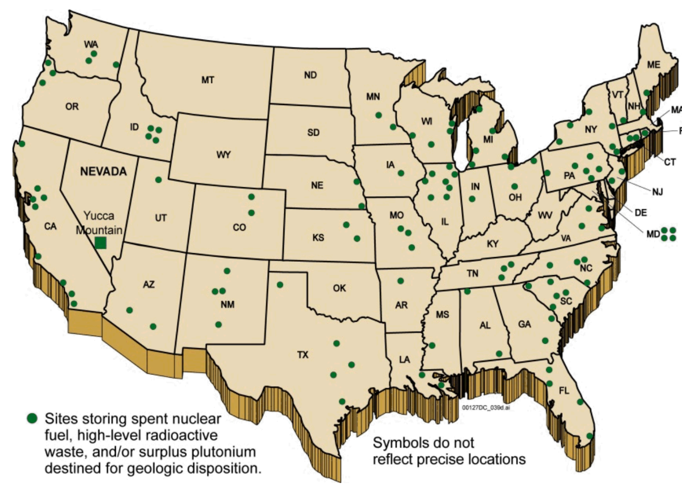
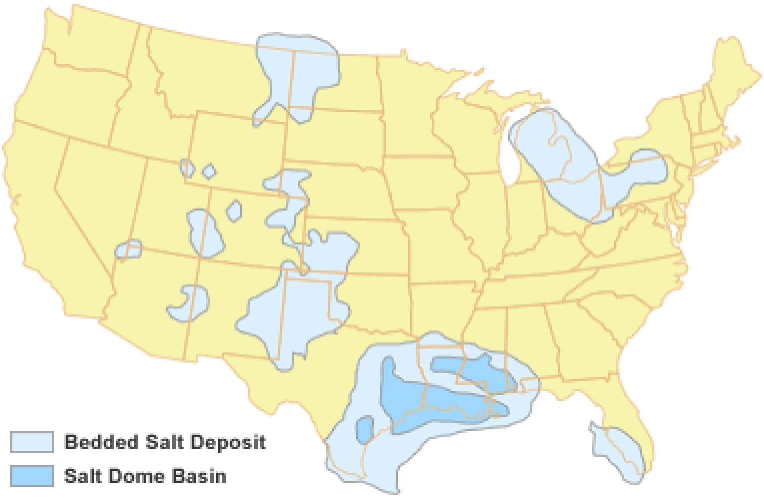
Nuclear Fuel Cycle Sustainability

- **20% U.S. electric power from commercial NPPs**
- **More than 2000-2300 metric tons of used fuel generated per year**
- **Permanent geologic disposal is needed for long-term sustainability of the nuclear fuel cycle**
- **In mid-1950s, NAS committee of earth scientists concluded that natural underground rock salt formations are among the most favorable disposal medium**



Geologic Medium - Why Salt?



- Salt rock occurs widely throughout the U.S.
- Is essentially impermeable
- Is self-sealing (slowly deforms under stress – creeps)
- Is thermally conductive so readily dissipates heat from the waste
- Is easy to mine, yet strong enough to allow creation of large rooms for disposal of waste
- Focus here on favorable properties, from a computational modeling perspective, regarding its potential use for a geologic HLW repository

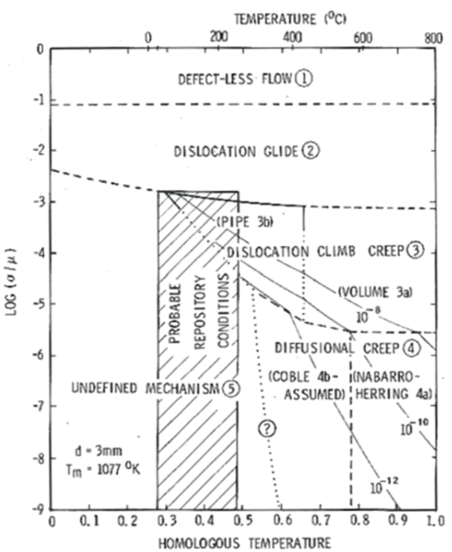
Computational Model for Use in the Development of a Repository

$$\sigma_{ij,j} + \rho b_j = \rho a_j \longrightarrow \sigma_{ij,j} + f_i = 0$$

$$e_{ij} = \frac{1}{2}\left(u_{i,j} + u_{j,i} + u_{k,j}u_{k,i}\right)$$

$$\dot{e}_{ij} = -\frac{\nu}{E}\dot{\sigma}_{kk}\delta_{ij} + \frac{1+\nu}{E}\dot{\sigma}_{ij} + \dot{e}^{c}_{ij} + 3\alpha\dot{T}\delta_{ij}$$

Governing Mathematical Equations



$$\dot{\varepsilon}^{c}_{ij} = F\dot{\varepsilon}_s \frac{\partial\bar{\sigma}}{\partial\sigma_{ij}}$$

$$\dot{\varepsilon}_s = \sum_{i=1}^{3}\dot{\varepsilon}_{s_i}$$

$$F = \begin{cases} e^{\Delta[1-\zeta/\varepsilon^*_t]^2}, & \zeta < \varepsilon^*_t \\ 1 & \zeta = \varepsilon^*_t \\ e^{-\delta[1-\zeta/\varepsilon^*_t]^2} & \zeta > \varepsilon^*_t \end{cases}$$

$$\dot{\zeta} = (F-1)\dot{\varepsilon}_s$$

MD Creep Constitutive Model

Key factors in the development of a repository:

- A sound design of the system
- Validated computational models and tools to permit crafting system designs with confidence
- Acceptable techniques for evaluating (assessing) the design's performance by methods known to be valid

$$\left\{\sum_N \int_{ve} B\sigma dV\right\} = \{F\}$$

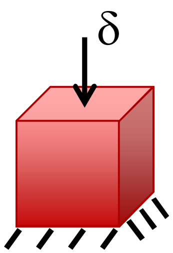
$$\{R\} = \left\{\sum_N \int_{ve} B\sigma dV\right\} - \{F\}$$

Discretization; Solution Technique; Integration of Constitutive Model; Adaptive Time-Stepping; Stability; Accuracy; etc.

FEM Discretized Version of Field Equations

Building Confidence in the Computational Capability

- Validated through a deliberate systematic process that includes exercising the model
  - to solve basic problems (ones with known solutions, if possible);
  - comparing model response against behavior of natural known phenomena;
  - conducting laboratory, bench-scale, and field tests to evaluate the performance of the model's predictions; and
  - conducting in-situ tests to compare predictive results of the model with actual underground data



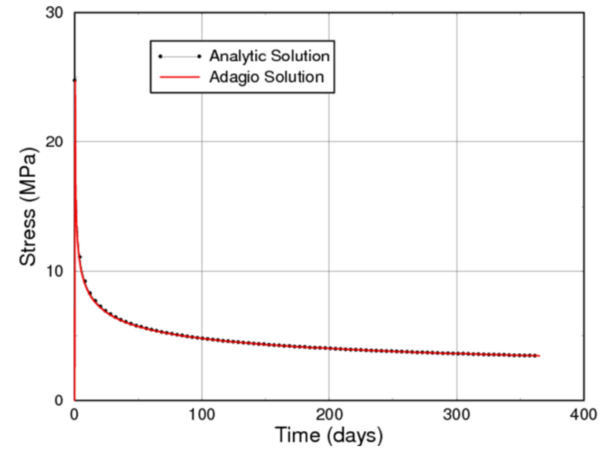
Creep Relaxation Problem

$$\delta = 0.001 \quad E = 24.75 \times 10^{9} \quad \nu = 0$$

$$D = 5.79 \times 10^{-36} \quad n = 4.9 \quad Q/(RT) = 20.13$$

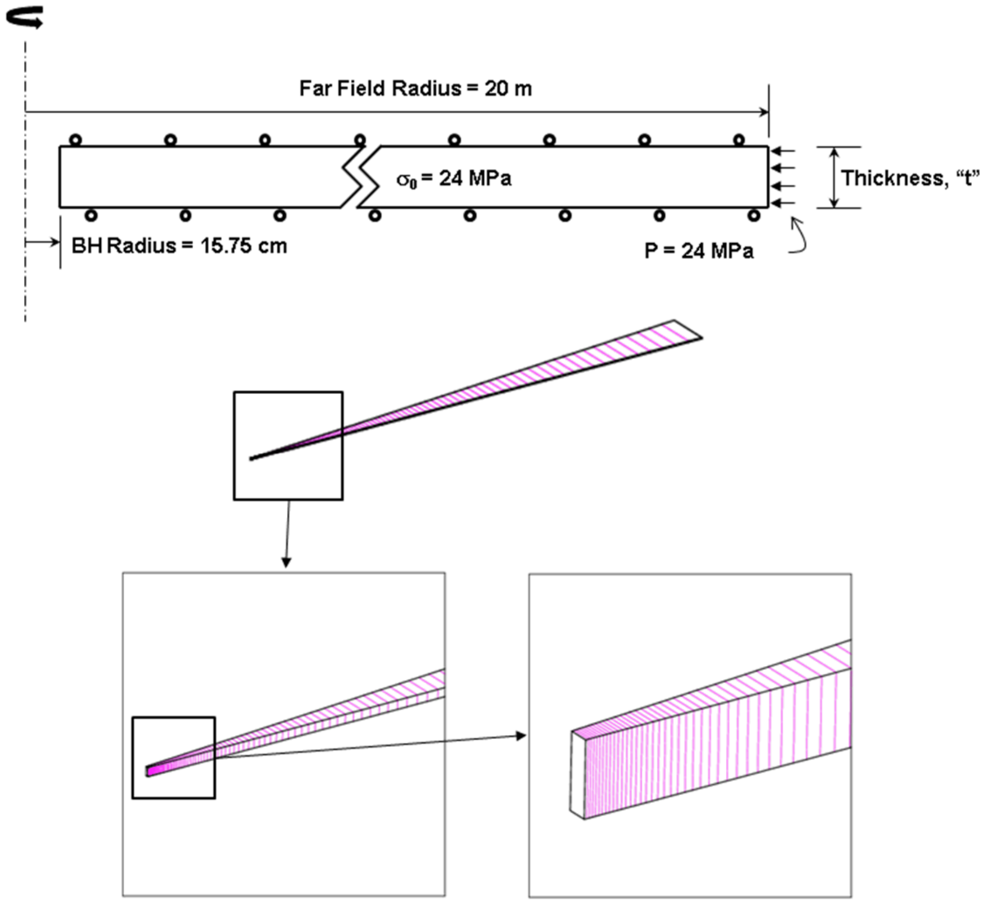
$$-\frac{\dot{\sigma}}{E} = \dot{\varepsilon}_c = D\sigma^n e^{-Q/RT}$$

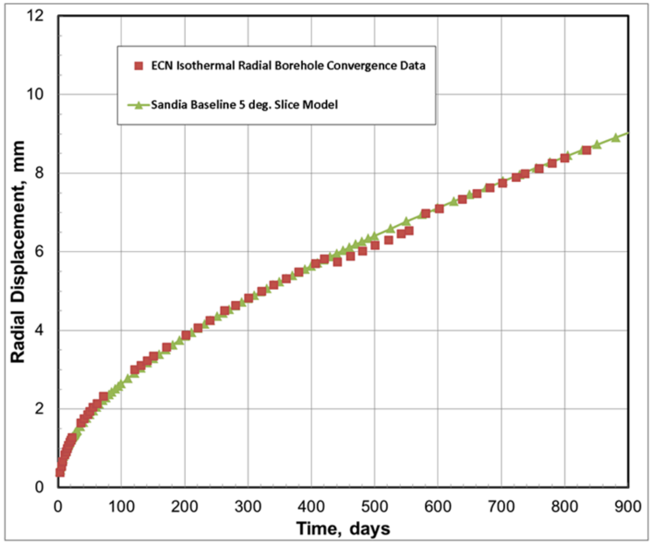
$$\sigma(t) = \left[\sigma^{1-n}(0) + EDe^{-Q/RT}(n-1)t\right]^{1/(1-n)}$$



Examples of Bench-Scale Field Test Comparisons

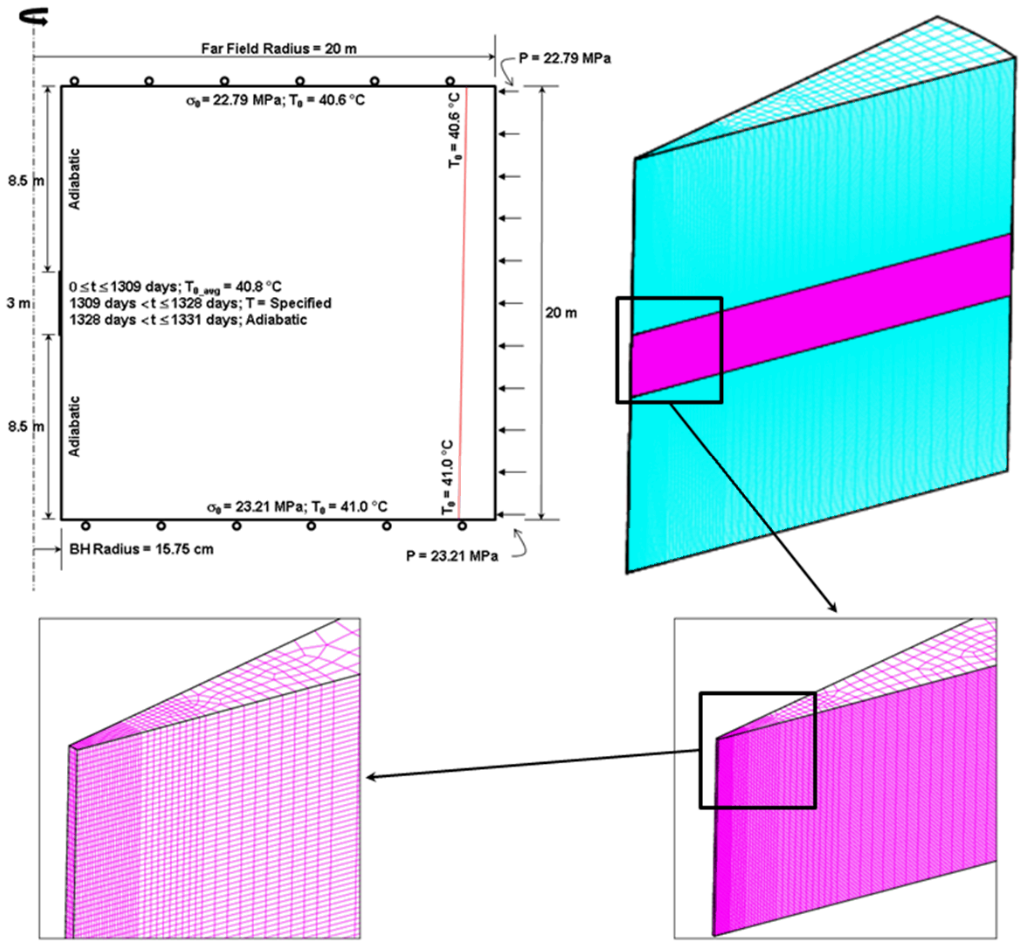
Isothermal Free Convergence Test

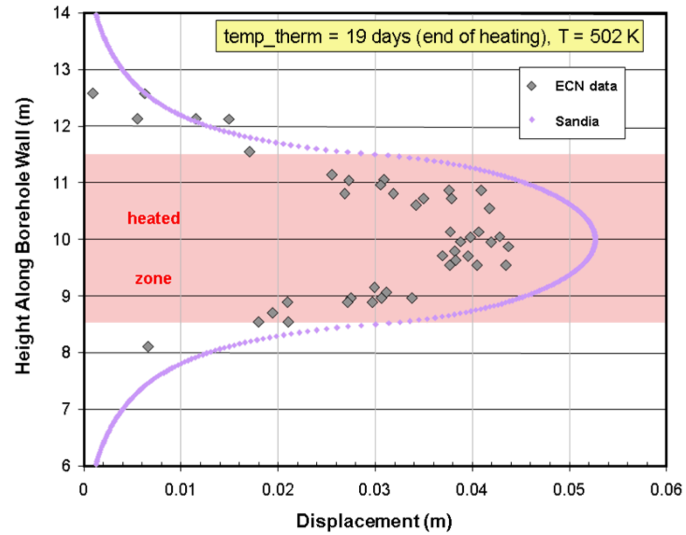




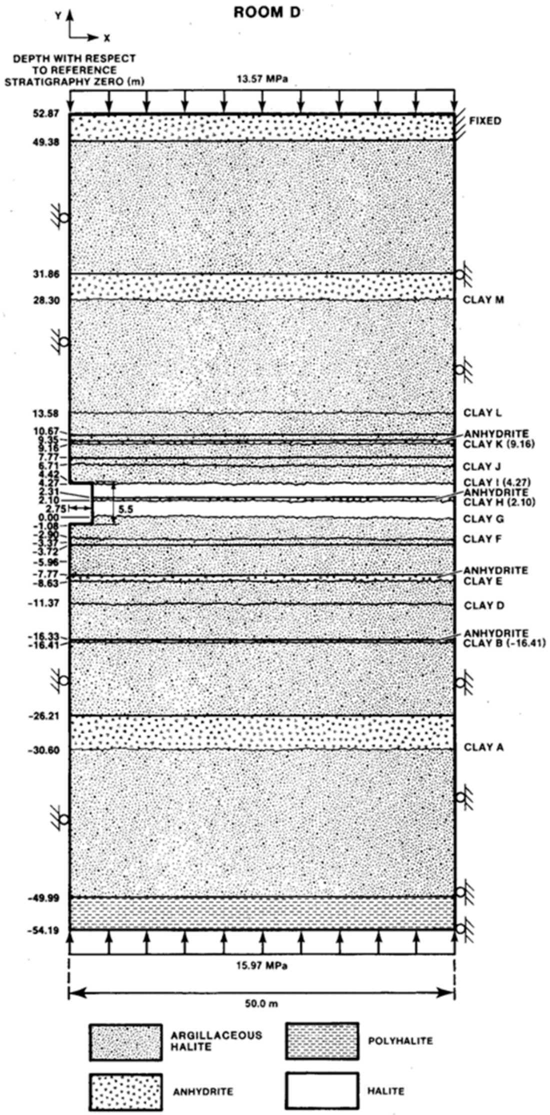
Examples of Bench-Scale Field Test Comparisons

Heated Free Convergence Probe Test

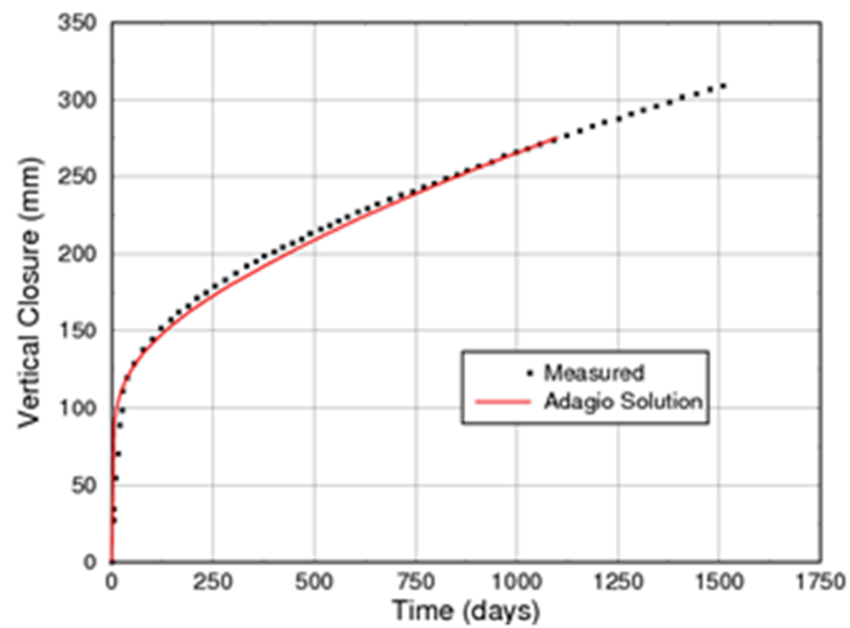




Example of Comparisons to In-Situ Full-Scale Experiment



Isothermal Mining Development Room
(WIPP Room D)



Summary and Conclusions

- Various deep geologic disposal medium options are open for consideration once again
- This work focused on addressing the favorable creep properties and behavior of geologic rock salt, from the computational modeling perspective, as it relates to its potential use as a medium for a deep geologic repository
- The various components that make up a computational modeling capability to address the thermo-mechanical behavior of rock salt over a wide range of time and space have been presented
- Several example salt calculations were also presented to demonstrate the applicability and validity of the modeling capability described to address repository-scale problems
- The evidence shown points to a mature computational capability that can generate results relevant to the design and assessment of a potential rock salt HLW repository
- The computational capability described here can be used to help enable fuel cycle sustainability by appropriately vetting the use of geologic rock salt for use as a deep geologic disposal medium