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Thermal-Hydrologic-Mechanical Modeling of a Generic Salt High-Level Radioactive Waste Repository

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Disposal of High Level Radioactive Waste in a Geologic Repository in Salt

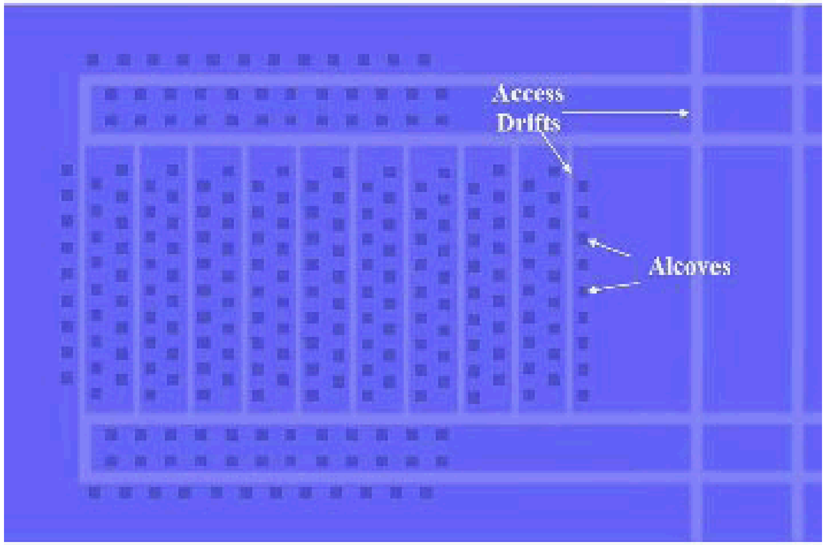
- The low permeability, low porosity, and creep mechanical behavior of intact and crushed salt backfill are important isolation attributes
- Relatively high thermal conductivity of intact and consolidated salt enhances heat transport away from the waste, resulting in reduced peak temperatures
- Geochemically reducing conditions limit solubility and enhance the sorption of radionuclides

Numerical Simulation of Thermal-Hydrologic-Mechanical Processes

- Decay heat from SNF and HLW would affect the thermal, hydrologic and mechanical behavior of the repository and host rock
- Generic repository in bedded salt considered
- Repository nominal depth - 650m
- Decaying heat from high level radioactive waste
- For THM simulations SNL's Sierra suite of codes: Adagio, Aria and Arpeggio were used

Disposal Concept

- Disposal concept considered includes a series of panels with individual rooms each containing alcoves.
- Each alcove designed for one canister/waste package
- Access drifts included between panels
- Alcoves to be covered with crushed salt backfill



Disposal panel layout (Clayton, 2010)

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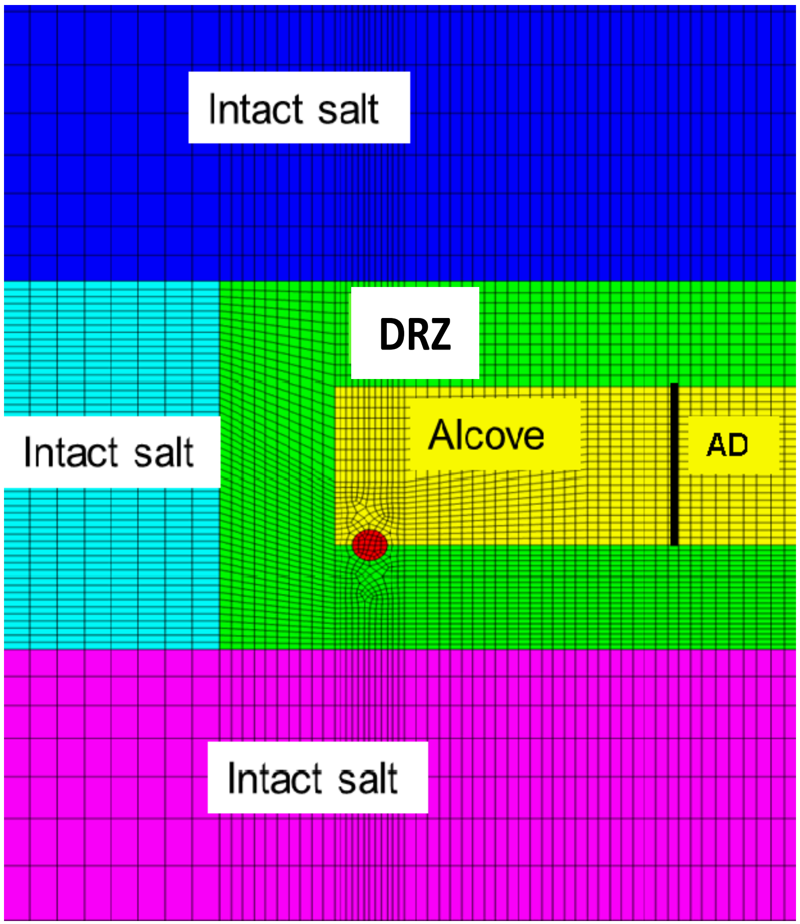
Model Set-up



- 3-D grid extending 30 m above and below repository
- Model includes intact salt host rock, disturbed rock zone (DRZ) and crushed salt backfill
- Alcove with one canister/ waste package with a diameter of 0.61 m and 2.7 m long
- Mesh with 175,520 cells

Input Parameters

- The TM simulations used a salt constitutive model developed by Callahan (1999)
- Thermal conductivity of crushed salt backfill as a function of temperature and porosity
- For permeability-porosity relations experimental data were used
- Crushed salt backfill permeability was calculated using porosity data obtained from TM simulations
- Decaying heat with 8.4 kW initial heat load (Clayton and Gable, 2009)

Base Case Material Properties and Input

Property	Intact Salt	DRZ	Crushed Salt Backfill	Waste
Porosity	0.01	0.014	varying	-
Permeability(m^2)	$1x\ 10^{-21}$	$1x\ 10^{-17}$	function of porosity	-
Thermal conductivity (W/m-K)	Function of temperature	Same as intact salt	Function of temperature and porosity	2
Specific heat (J/kg-K)	931	931	931	840
Grain density (kg/m^3)	2190	2190	2190	2200
Initial liquid saturation	1.0	0.5	0.05	-
Residual liquid saturation	0.05	0.05	0.01	-

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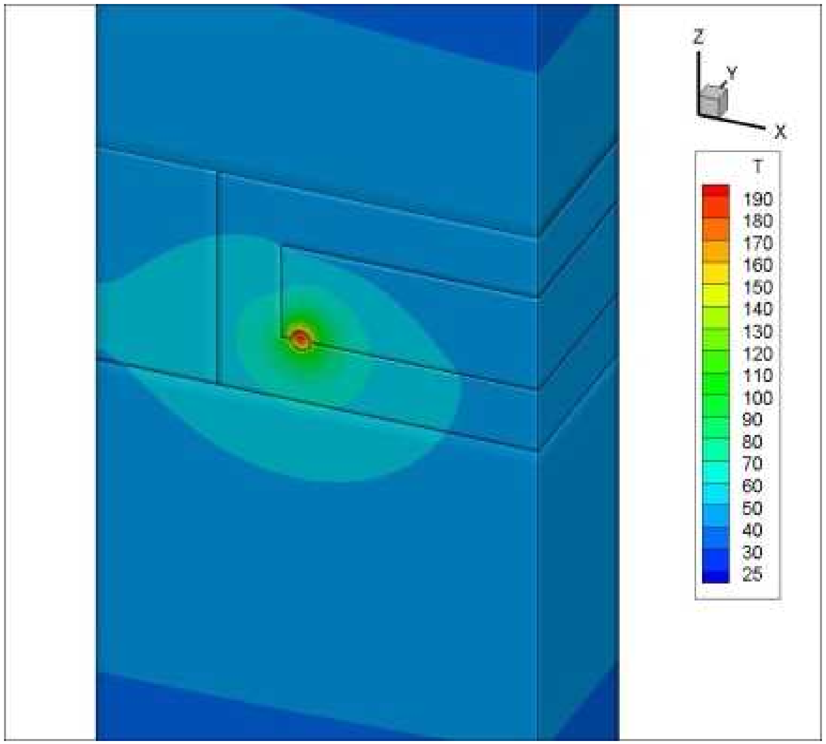
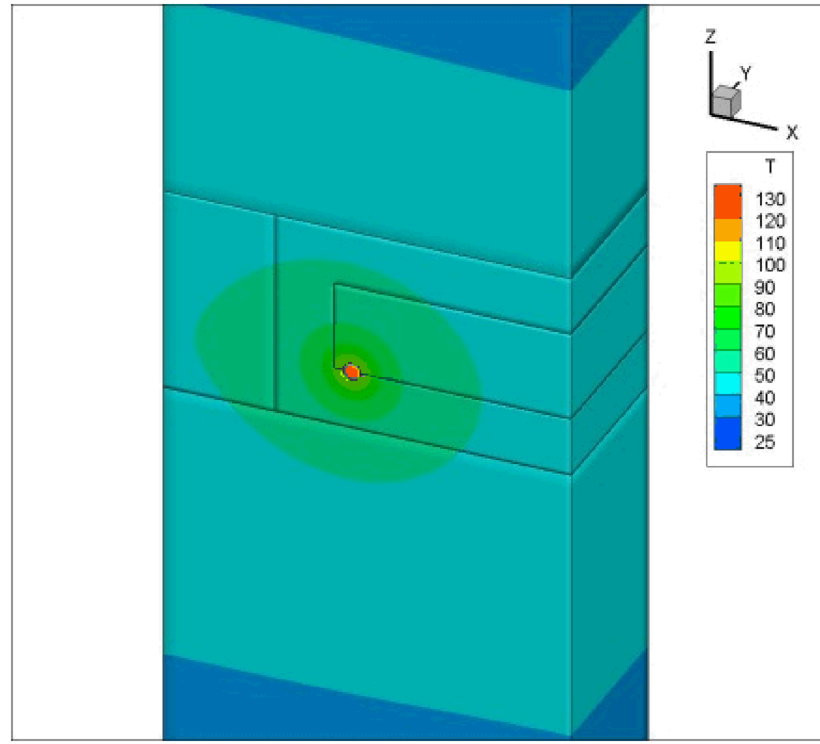
1. Thermal-Hydrologic Simulations

- Identify parameters that most influence thermal response of system in the presence of two-phase flow
- Initial conditions:
  - intact salt and DRZ: 25 °C and 12 MPa
  - crushed salt backfill: 25 °C and 1 atm.
- Boundary conditions:
  - Constant temperature at top and bottom
  - Constant pressure and no-flow at bottom
- Exercise: Compare TH processes in an uncompacted (base case) and a compacted crushed salt backfill
- An initial heat source of 2.4 kW was applied, corresponding to about 50 years surface storage

Thermal-Hydrology Simulation Results: Distribution of Temperature (5 years)



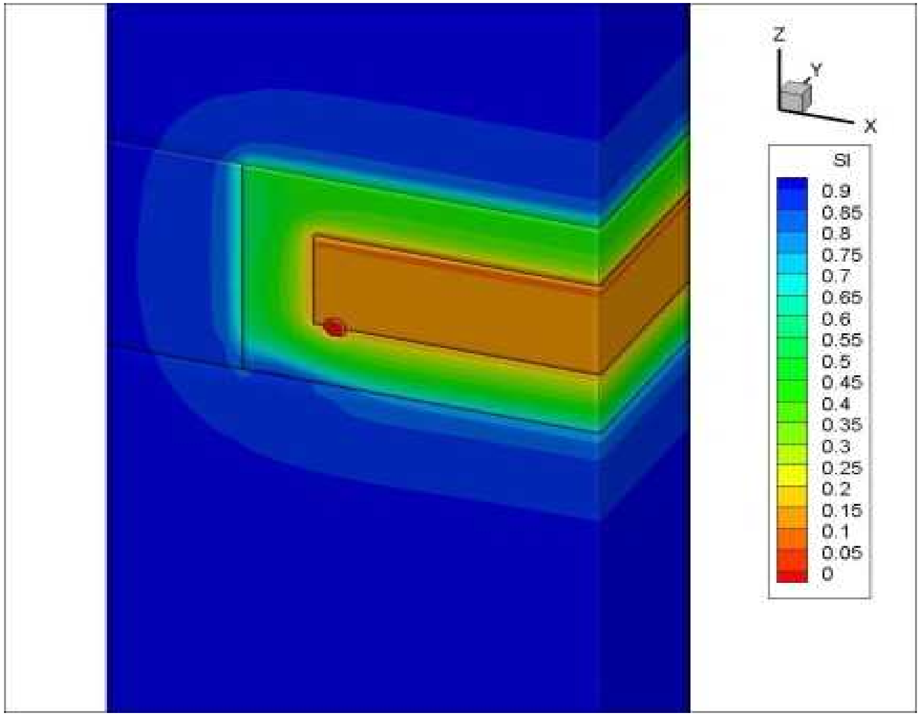
Uncompacted Case

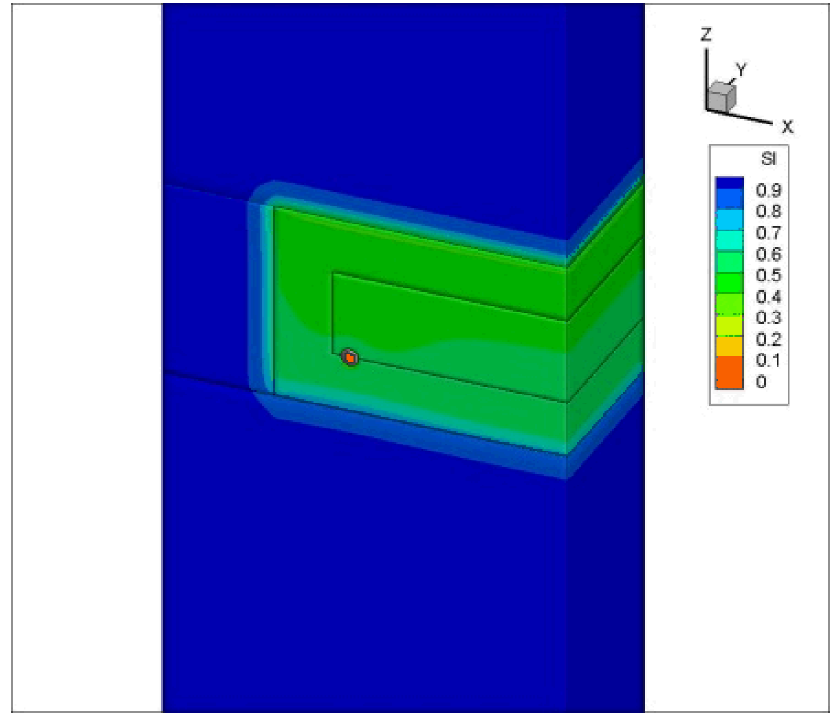


Compacted Case

- **Compaction of the crushed salt backfill has a significant effect on peak temperature response and spread of thermal front**

Thermal-Hydrology Simulation Results: Distribution of Saturation (5 years)

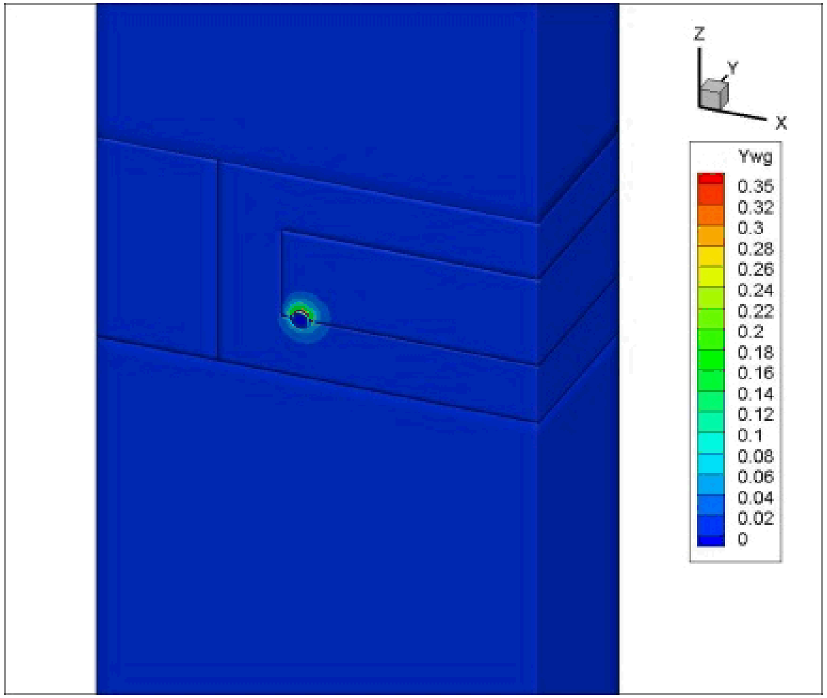




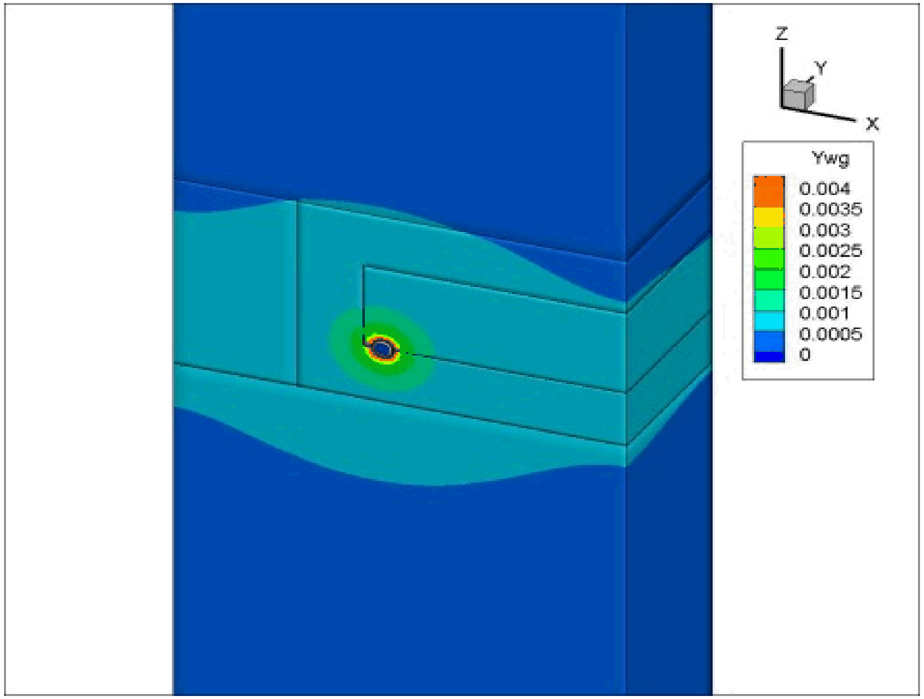
Uncompacted Case **Compacted Case**

- Movement of fluid is dependent on thermal processes and hydraulic conditions

Thermal-Hydrology Simulation Results: Distribution of Mass Fraction of Vapor (5 years)



Uncompacted case



Compacted Case

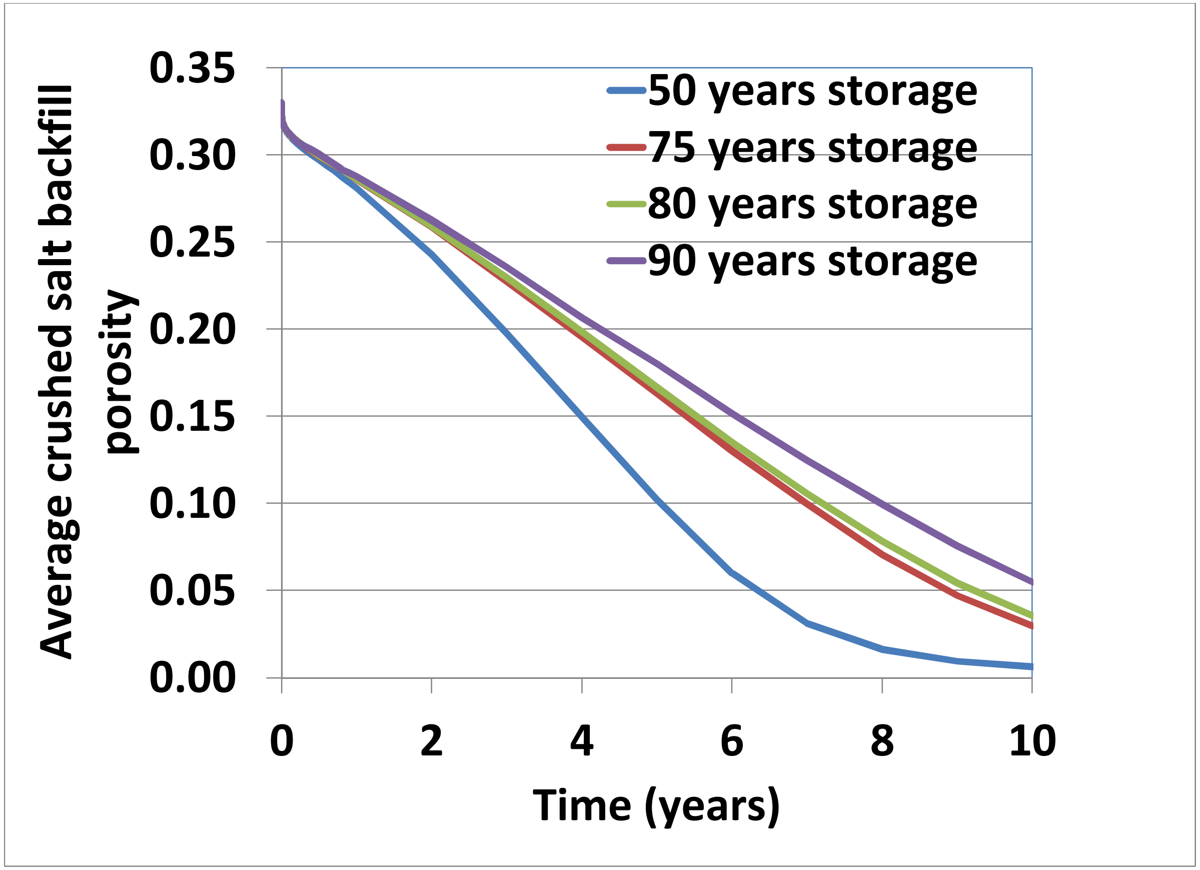
- **The reduced peak temperature has also affected water vapor generation**

2. Thermal-Hydrologic-Mechanical Simulations

- One-way THM coupling: Outputs of TM simulations were used in separate TH simulations
- TM simulations carried out to provide average porosity as a function of time for the crushed salt backfill
- crushed salt backfill permeability and thermal conductivity obtained based on porosity data

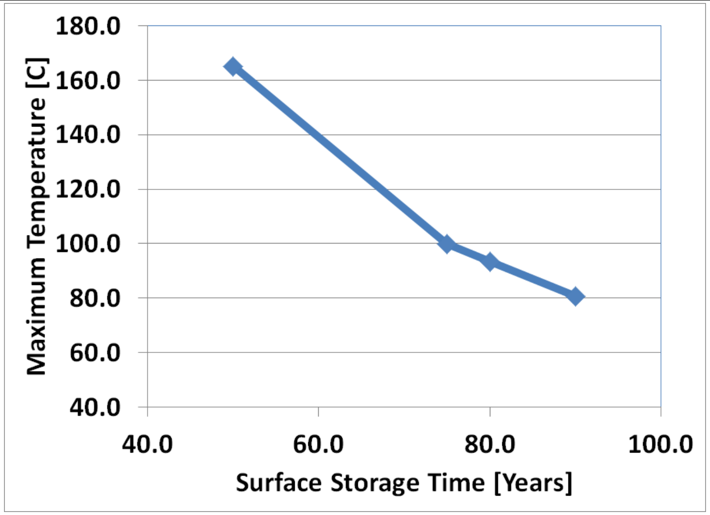
Thermal-Mechanical Simulation Results: Average Crushed Salt Backfill Porosity

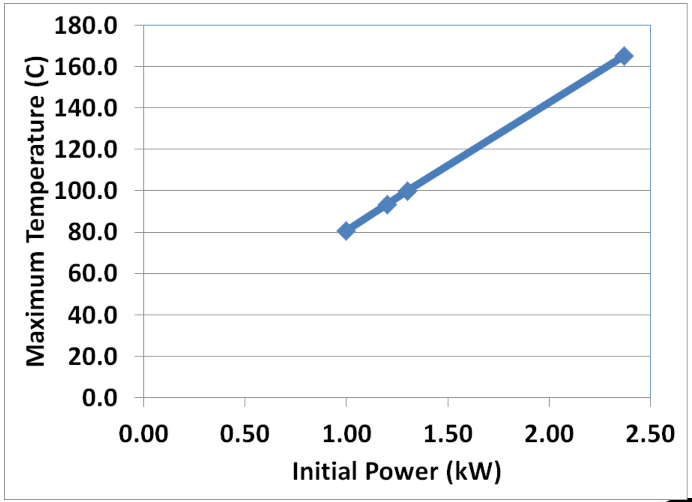
- 1% moisture in crushed salt backfill assumed



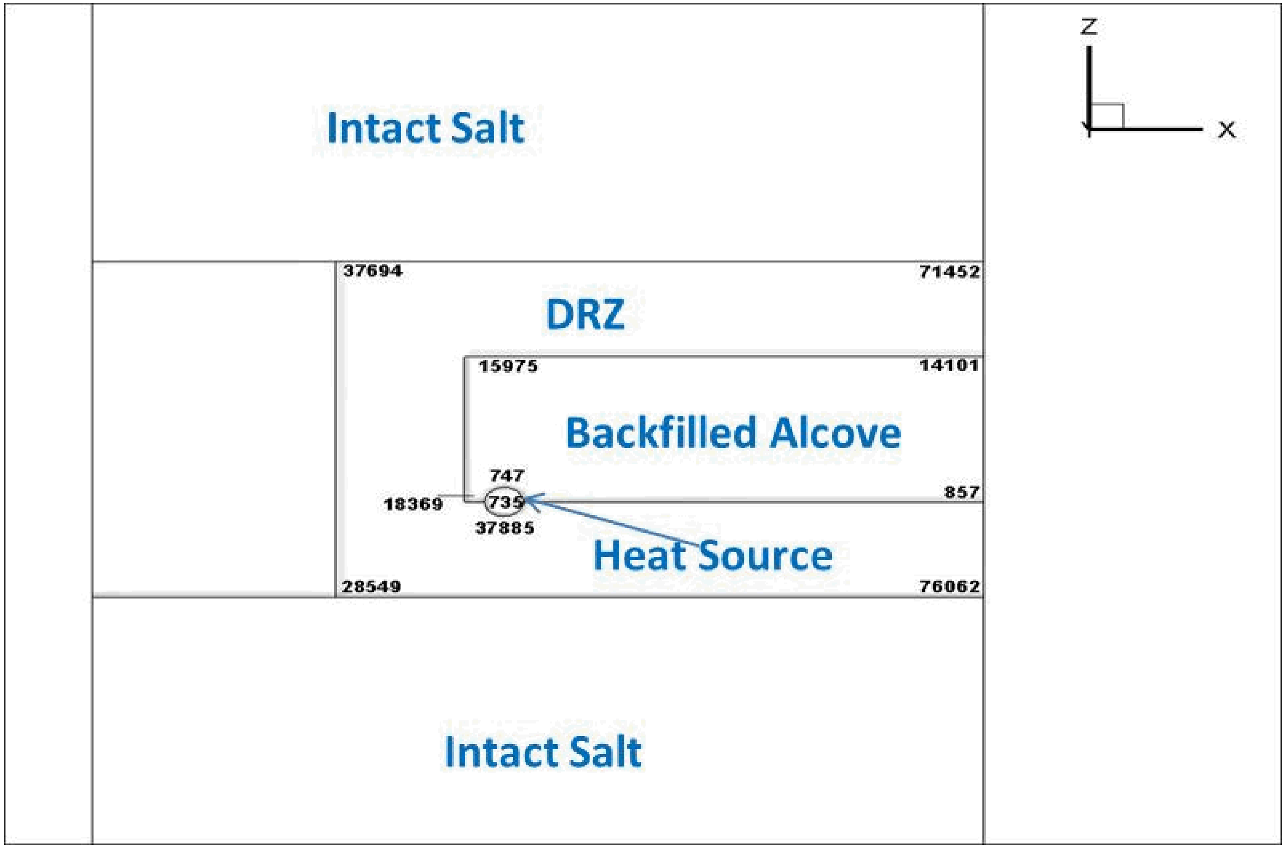
Thermal-Hydrologic-Mechanical Simulation Results: Peak Temperature

- Simulations conducted for selected surface storage times and corresponding initial power.
- Maximum temperature at heat source surface is a function of surface storage time/initial power
- Linear correlation between initial power and peak temperature





Thermal-Hydrologic-Mechanical Modeling: Locations of Selected Nodes



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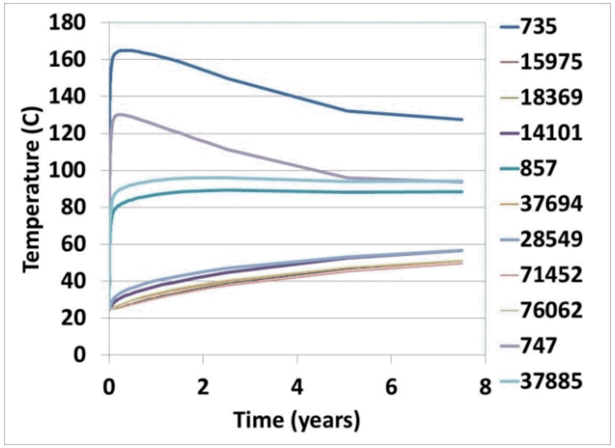
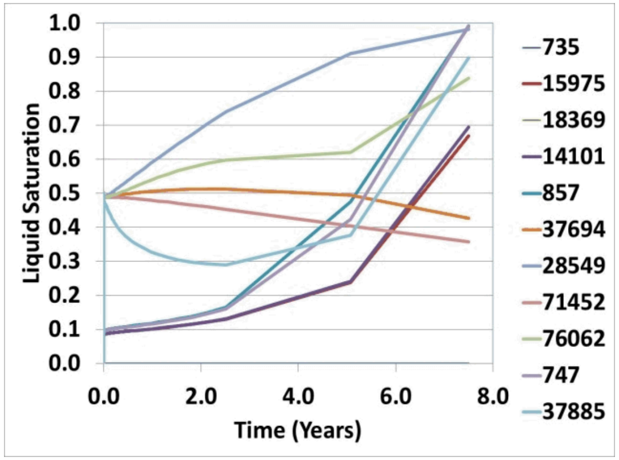
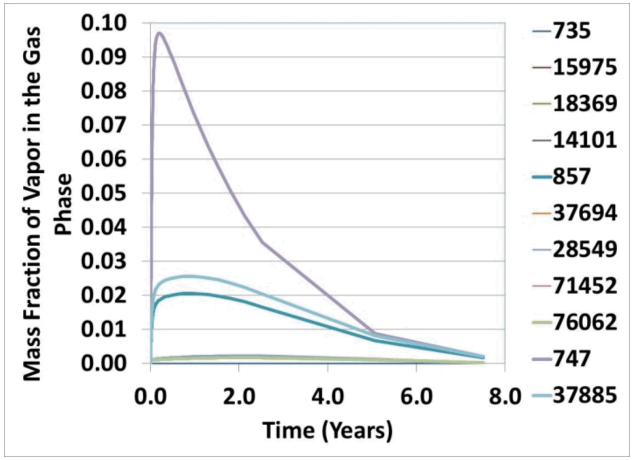
Temperature, Saturation and Mass Fraction of Vapor at Different Locations

- **Simulation results of 50-year surface storage case shown**
- **Temperature decreases with distance from heat source, and also with time**
- **Results represent dry-out, re-saturation, and vapor movement**







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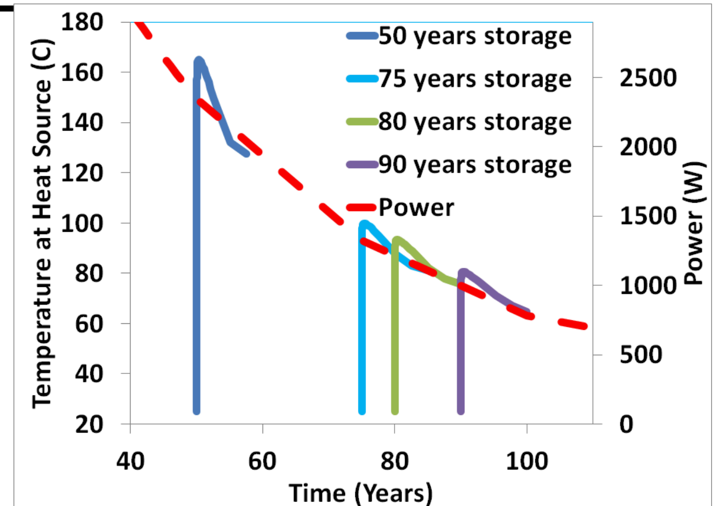
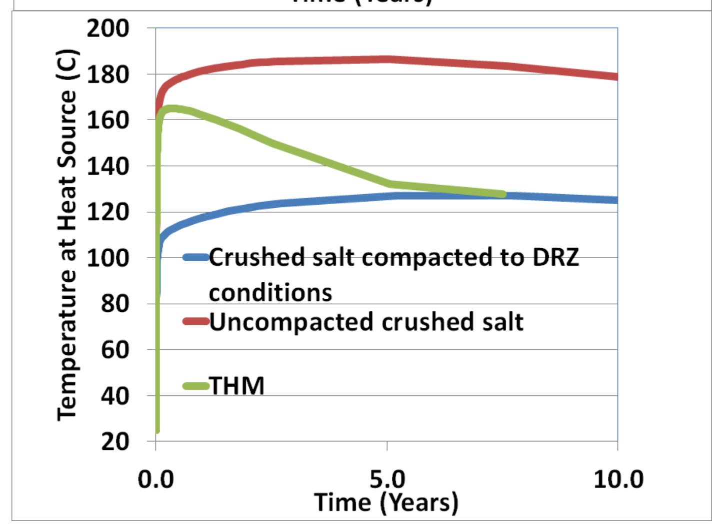
Temperature at Surface of Heat Source

- Top figure: temperature at heat source follows decay heat for different surface storage times
- Bottom figure: different simulation cases for the 50-year storage time modeling case
  - THM simulation temperature results bounded by the compacted and uncompacted crushed salt backfill TH results





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Conclusions

- TH and THM modeling provided preliminary output of thermal, mechanical and hydrologic processes in a salt repository
- Peak temperature at surface of heat source is mainly a function of waste type, surface aging, and consolidation of backfill
- Thermal propagation reaches well into the intact salt, mainly as a result of conduction
- Propagation of water vapor is limited by the nearly-impermeable intact salt, consolidation of the crushed salt, and the thermal decay of the heat source
- Recommendations for future work:
  - Two-way THM modeling
  - Include salinity of fluids
  - Use of different heat sources
  - Sensitivity analysis