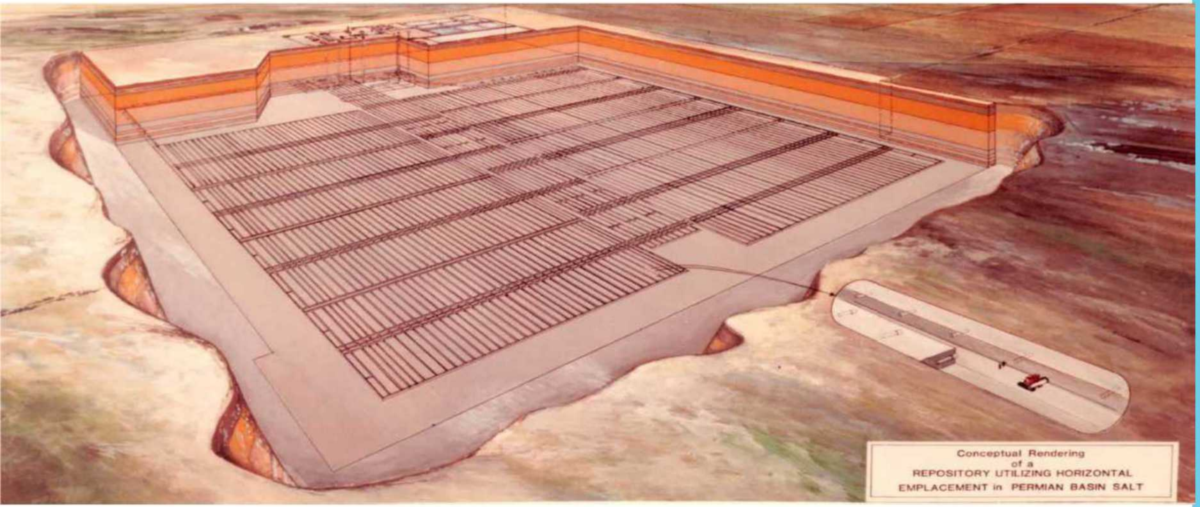
SAND2020-9234PE

RANGERS Project

Summary of SNL Thermal Modeling of DPC Disposal in Salt



PRESENTED BY

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This is a technical paper that does not take into account contractual limitations or obligations under the Standard Contract for Disposal of Spent Nuclear Fuel and/or High-Level Radioactive Waste (Standard Contract) (10 CFR Part 961). For example, under the provisions of the Standard Contract, spent nuclear fuel in multi-assembly canisters is not an acceptable waste form, absent a mutually agreed to contract amendment.

To the extent discussions or recommendations in this paper conflict with the provisions of the Standard Contract, the Standard Contract governs the obligations of the parties, and this paper in no manner supersedes, overrides, or amends the Standard Contract.

This paper reflects technical work which could support future decision making by DOE. No inferences should be drawn from this paper regarding future actions by DOE, which are limited both by the terms of the Standard Contract and Congressional appropriations for the Department to fulfill its obligations under the Nuclear Waste Policy Act including licensing and construction of a spent nuclear fuel repository."

Outline

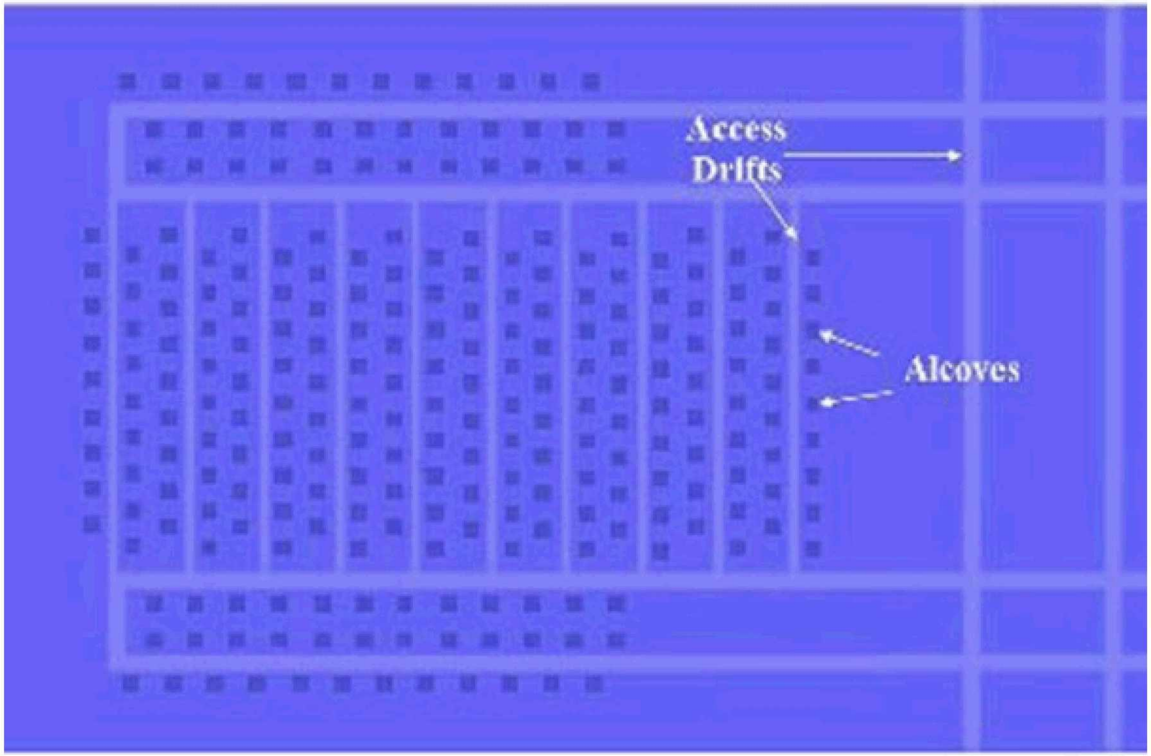
- Part I: Overview of previous modeling work at Sandia National Laboratories
- Part II: TM modeling of DPC disposal in salt using numerical codes
  - Model development
  - THM modeling results
- Part III: Thermal modeling of DPC disposal in salt using semi-analytical model
  - Model development
  - Thermal results

Part I: Overview of Previous Modeling Work at Sandia National Laboratories

- Various thermal modeling tasks have been carried out at Sandia for disposal in salt.
- Thermal-only modeling using semi-analytical models was used in the design of generic repositories to estimate repository footprint and peak temperatures.
- TM numerical modeling was conducted to study thermal conditions in the near-field together with mechanical processes.
- THM numerical modeling was done to study the effect of hydrologic (including vapor transport) conditions in addition to the TM processes.

Salt Disposal Concept for Standard Canisters

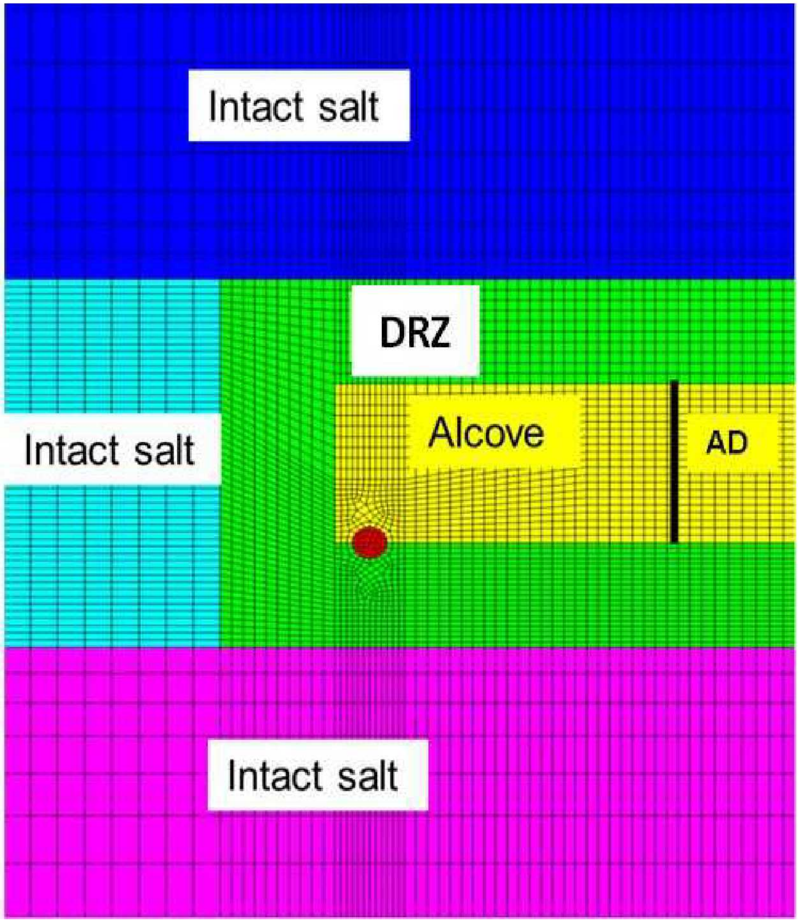
- Disposal concept considered includes a series of panels with alcoves
- Access drifts included between panels
- Alcoves to be covered with crushed salt backfill



Clayton (2010)

THM Modeling for Disposal in a Salt Repository

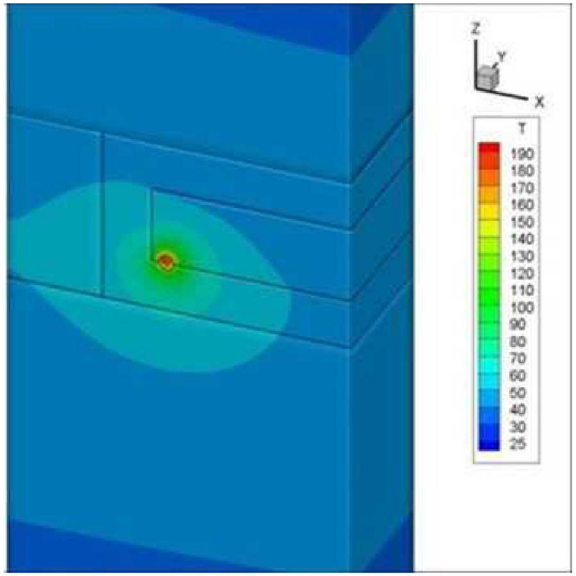
- 3-D grid extending 30 m above and below repository
- Model includes intact salt host rock, disturbed rock zone (DRZ) and crushed salt backfill
- Alcove with one canister/ waste package with a diameter of 0.61 m and 2.7 m long
- Mesh with 175,520 cells
- Sandia's Sierra suite of codes: Adagio, Aria and Arpeggio were used

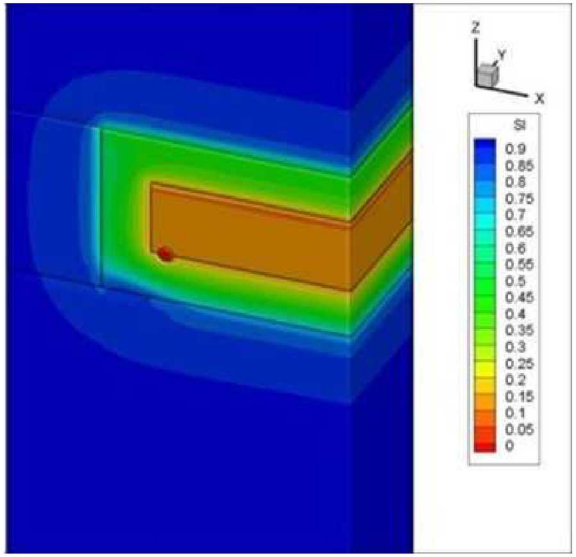


Hadgu et al. (2013)

THM Modeling Results

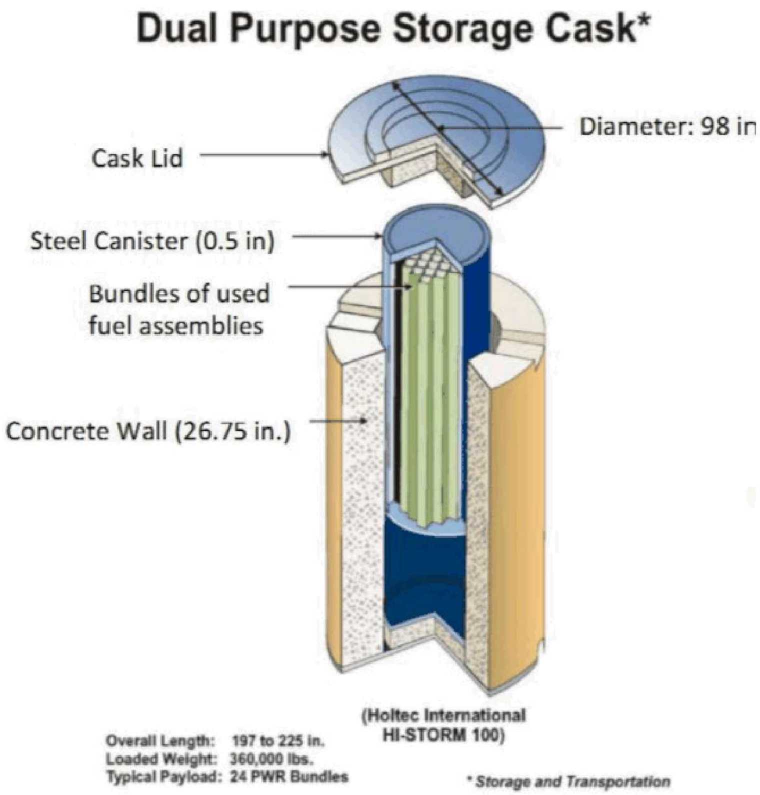
- The TM simulations used a salt constitutive model developed by Callahan (1999)
- Thermal conductivity of crushed salt backfill as a function of temperature and porosity
- For permeability-porosity relations experimental data used
- Initial conditions:
  - intact salt and DRZ: 25 °C and 12 MPa
  - crushed salt backfill: 25 °C and 1 atm.
- Boundary conditions:
  - Constant temperature at top and bottom
  - Constant pressure at top





Direct Disposal of Dual Purpose Canisters

- An Example of a dual-purpose canister inside a storage overpack (cask) (Hardin et al., 2015, Modified from Easton 2011)



- The TM and thermal analyses assumed the in-drift emplacement mode which is considered to be suitable for disposal of large, heavy packages

Part II: TM Modeling of Disposal in Salt

- For TM modeling Sandia based Sierra suite of codes were used.
- For the simulations creep models for intact and crushed salt were utilized. The method allows for mechanical consolidation of the crushed salt backfill which affects thermal properties of the backfill.
- The simulation looked at emplacement of waste packages in semi-cylindrical floor cavities and increasing out-of-reactor period to meet target temperature limit (assumed to be 200 °C).

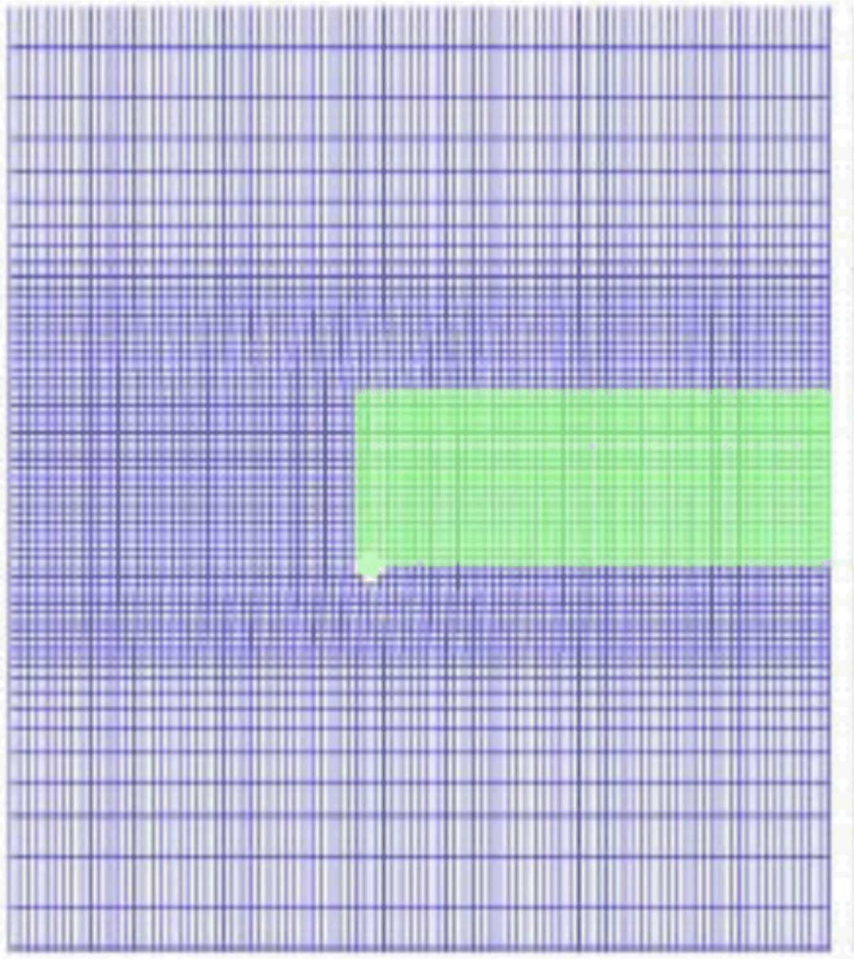
Thermal and Mechanical Properties for TM Modeling

Material	Thermal Conductivity (W/m K)	Specific Heat (J/kg K)	Density (kg/m^3)
Waste	1.0	840.0	2200.0
Intact Salt	Function of temp	931.0	2160(ρ_o)
Crushed Salt	Function of temp	931.0	$\rho_o(1-\phi)$

Material	Young's Modulus (Pa)	Poisson's Ratio	Thermal Expansion (K^{-1})
Heater	2.0E11	0.3	2.0E-06

- Intact salt modeled using the multimechanism-deformation (M-D) creep model (Munson et al. 1989).
- Crushed salt modeled using the crushed salt creep model (Callahan 1999).
- Waste assumed to respond elastically using the properties of steel.

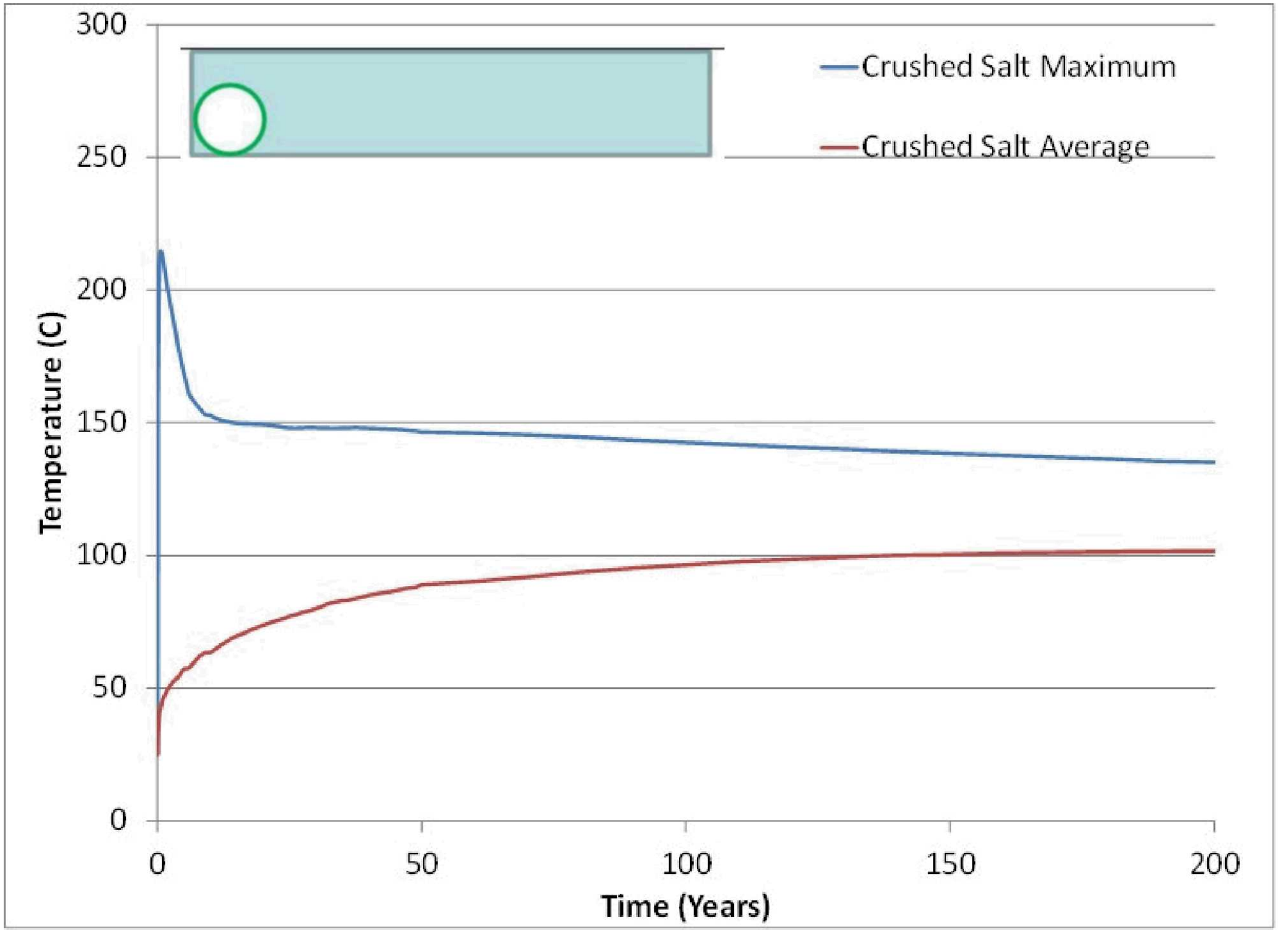
Near-Field Alcove Grid used for TM Modeling



Hardin et al. (2013), Hadgu et al. (2015)

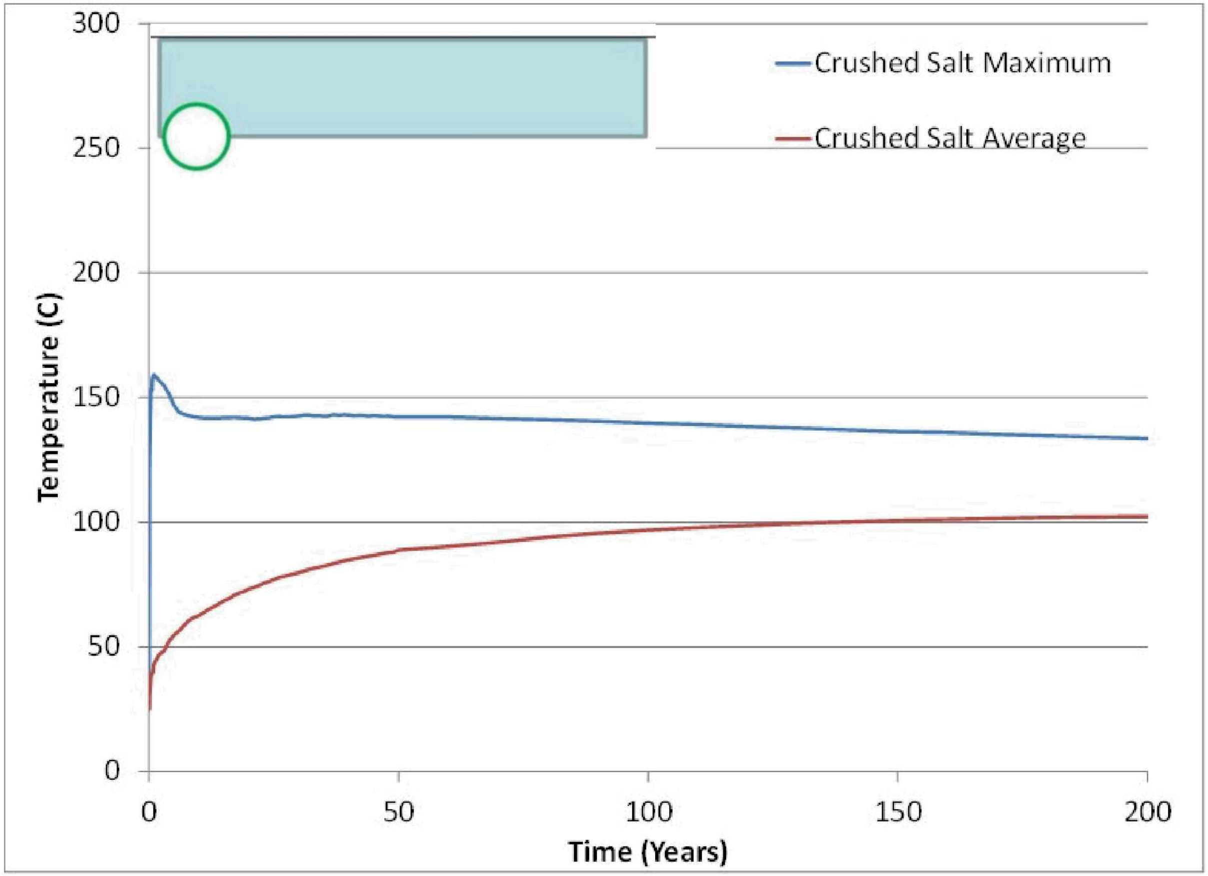
TM Modeling Results: Temperature Histories

- In-drift emplacement with 30-m waste package spacing, and fully coupled thermal-mechanical solution. 60 GW-d/MT, 100 years out of reactor. No floor cavity.



TM Results: Temperature Histories; Continued

- In-drift emplacement of 37-PWR size waste packages with 30-m spacing, and fully coupled thermal-mechanical solution. 60 GW-d/MT, 100 years out of reactor. run with floor cavity.

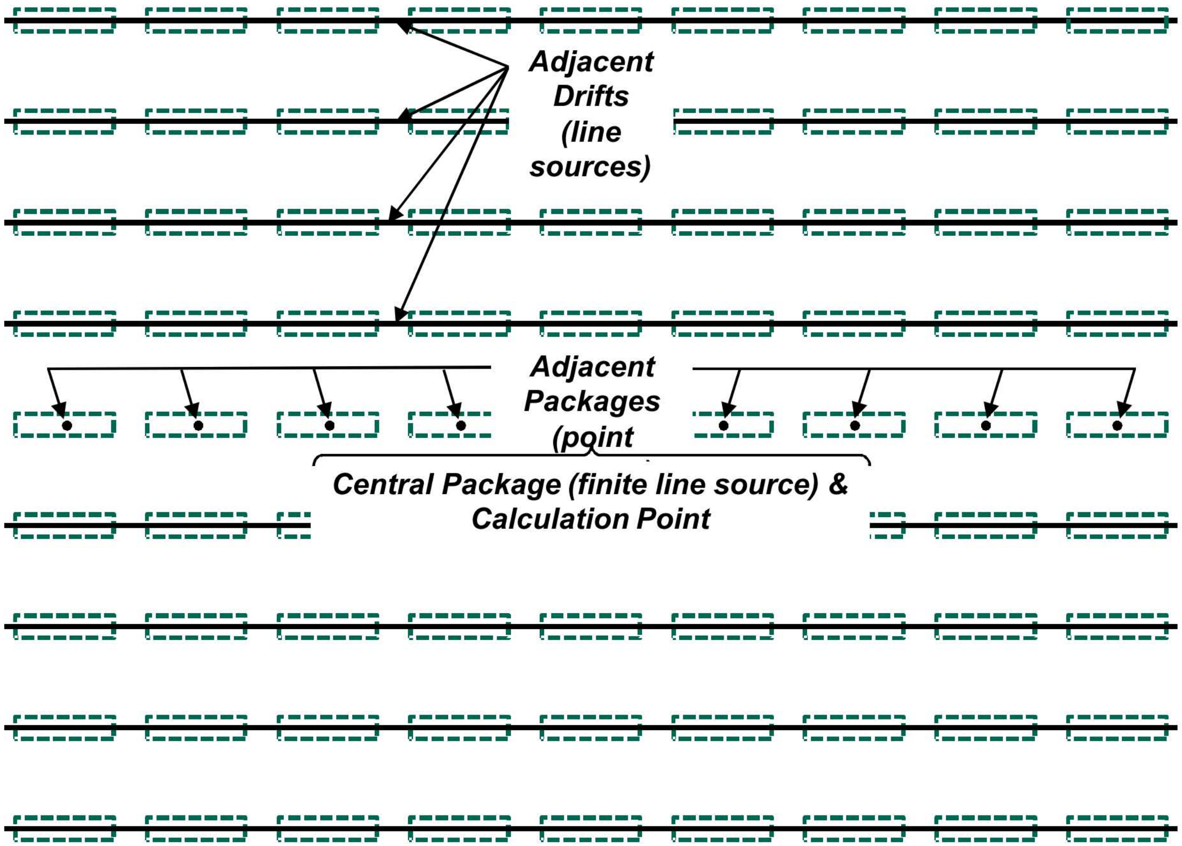


PART III: Thermal-Only Modeling using the Semi-Analytical Model

- Semi-analytical model used to simulate emplacement of DPCs.
- The repository was assumed to be at 500 m depth.
- Ambient average ground surface temperature of 15°C, and a natural geothermal gradient of 25°C/km were used.
- The disposal concept is based on DPCs placed in overpacks emplaced individually horizontally.

Representation of the Semi-Analytical Method

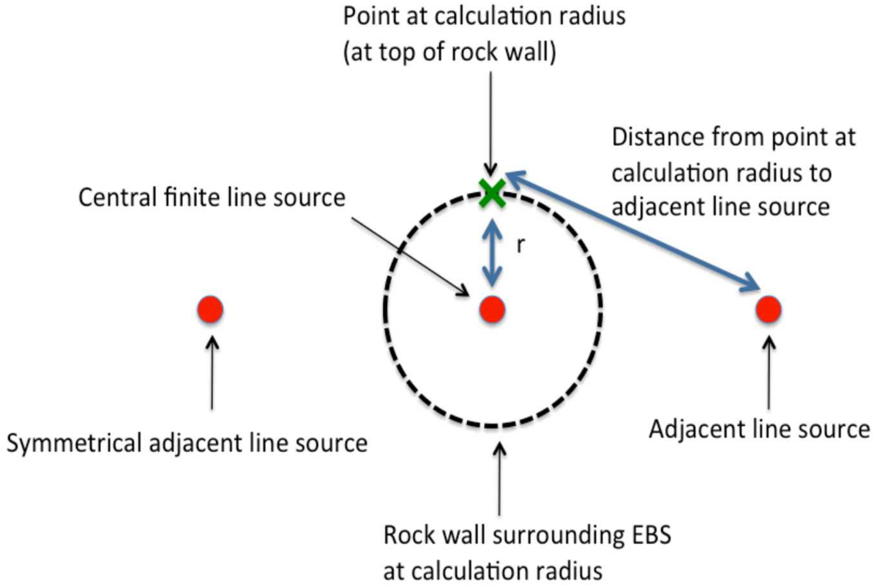
- Thermal-only analysis based on semi-analytical solution
- Based on method of superposition



Hardin et al. (2012)

Representation of the Semi-Analytical Method, Contd.

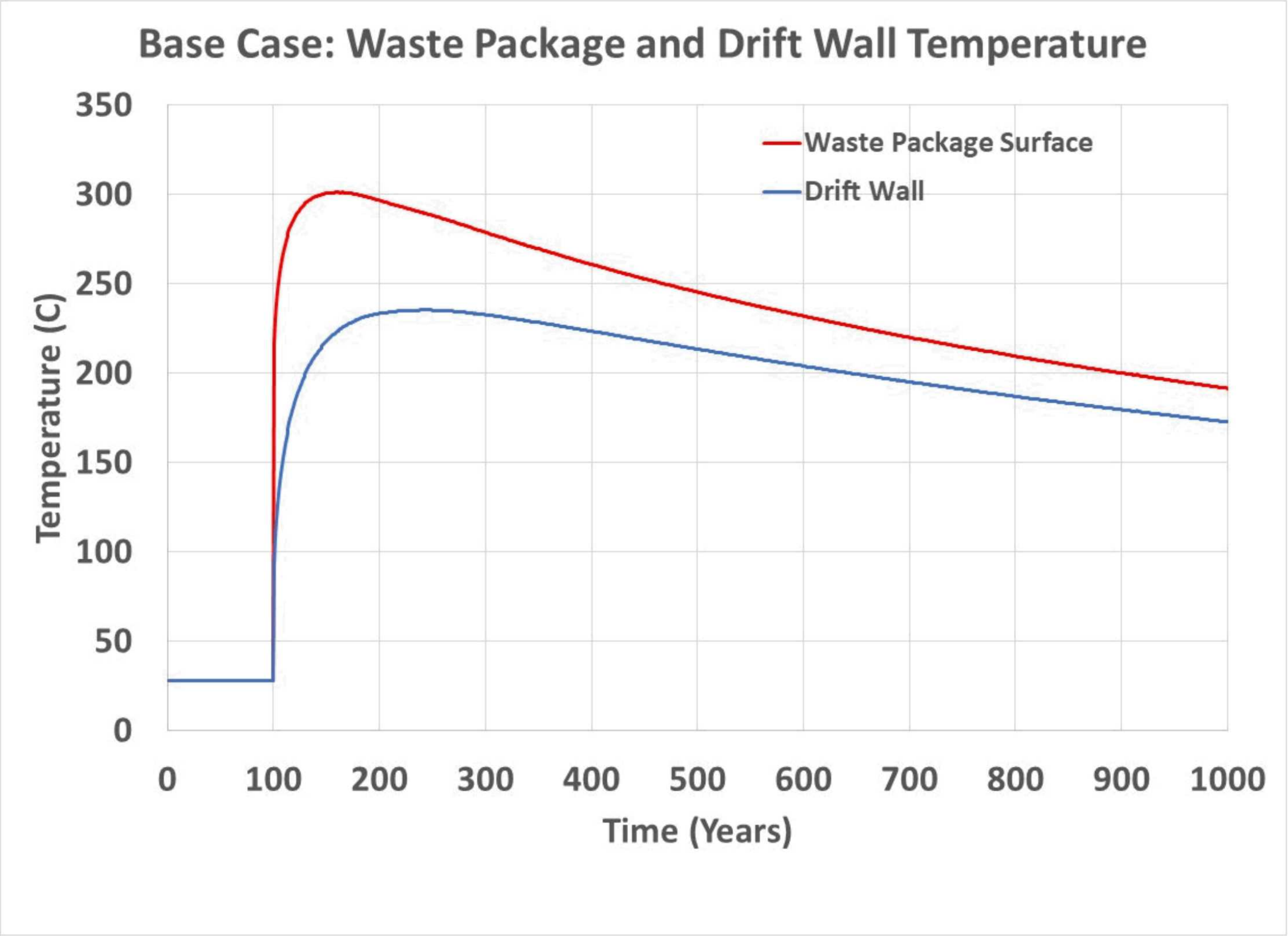
- MathCad-based semi-analytical transient thermal model
- Based on analytical solution of heat transport (i.e., Carlslaw and Jaeger, 1959)
- Model includes other processes such as radiation heat transfer and ventilation
- Thermal conduction solution: linear superposition of components



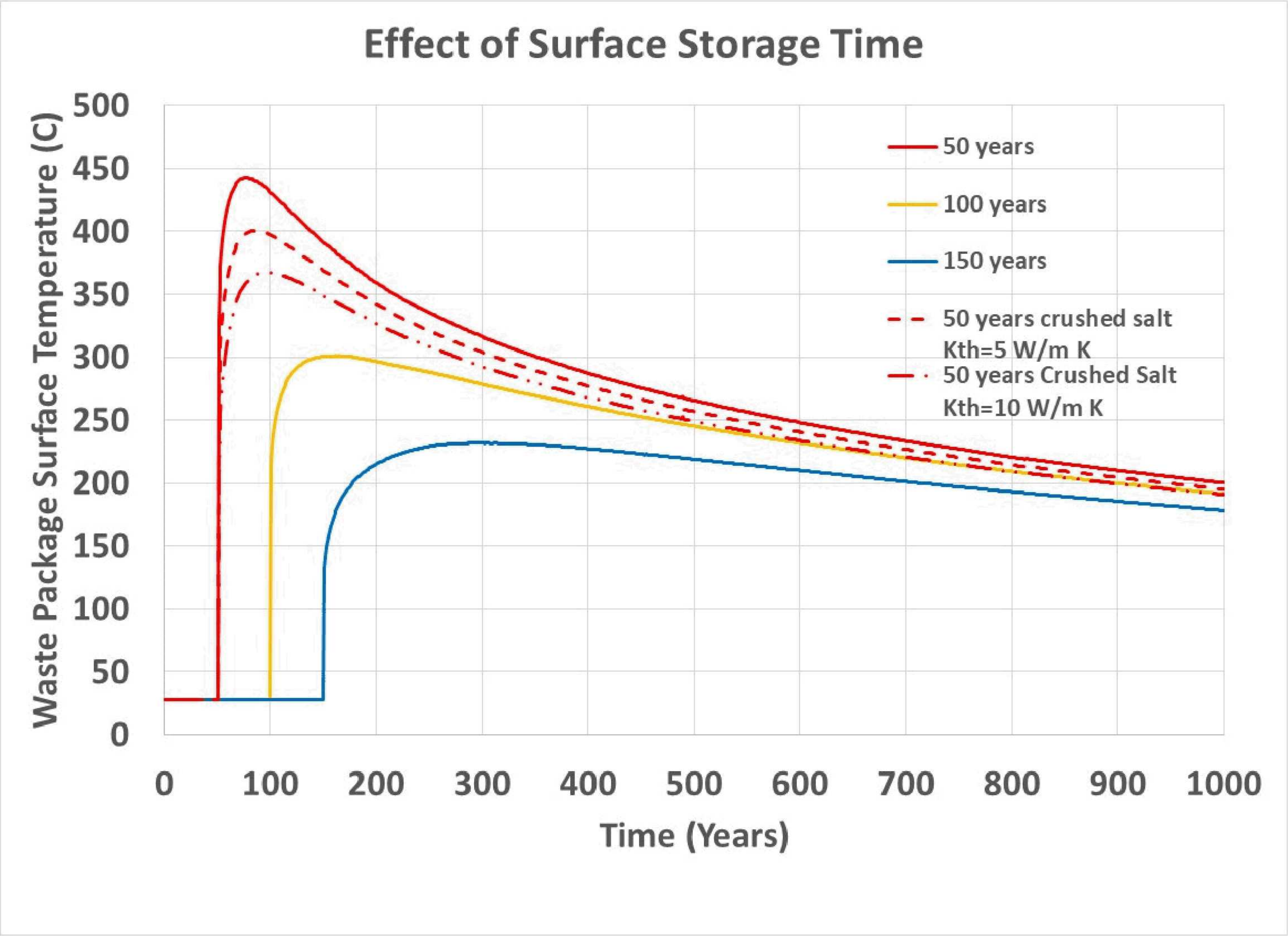
Input Parameters for Thermal Analysis

- Waste includes 37-PWR waste packages with 60 GW-d/MT burnup.
- Base Case Data:
    - drift diameter: 6.1 m
    - waste package diameter of 2.0 m with 5.6 m length
    - Drift spacing: 35 m
    - Waste package spacing: 10 m (center-to-center)
    - Thermal conductivity of intact salt: 3.2 W/m K
    - Thermal diffusivity: 1.57×10^{-6} m^2/sec
    - Thermal Conductivity of backfill: 3.2 W/m K
    - Surface storage time: 100 years
- For parametric study the following variations were made:
    - Surface storage time: 50.0, 150.0 years
    - Backfill thermal conductivity: 1.0, 2.0, 5.0 and 10.0 W/m K
    - Drift spacing: 50.0, 70.0 m
    - Waste package spacing: 15.0, 20.0 m

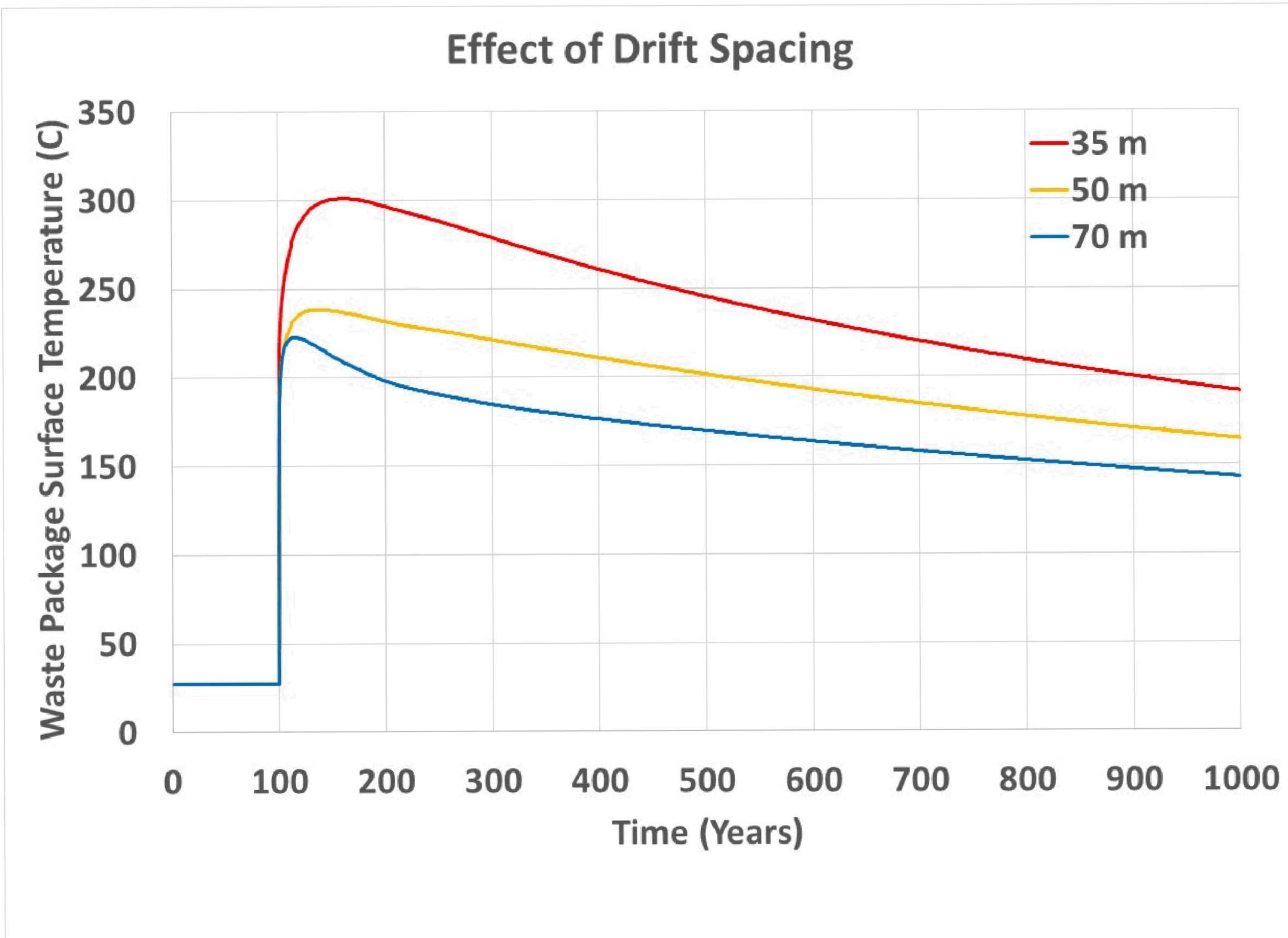
Results of Thermal Simulations: Base Case



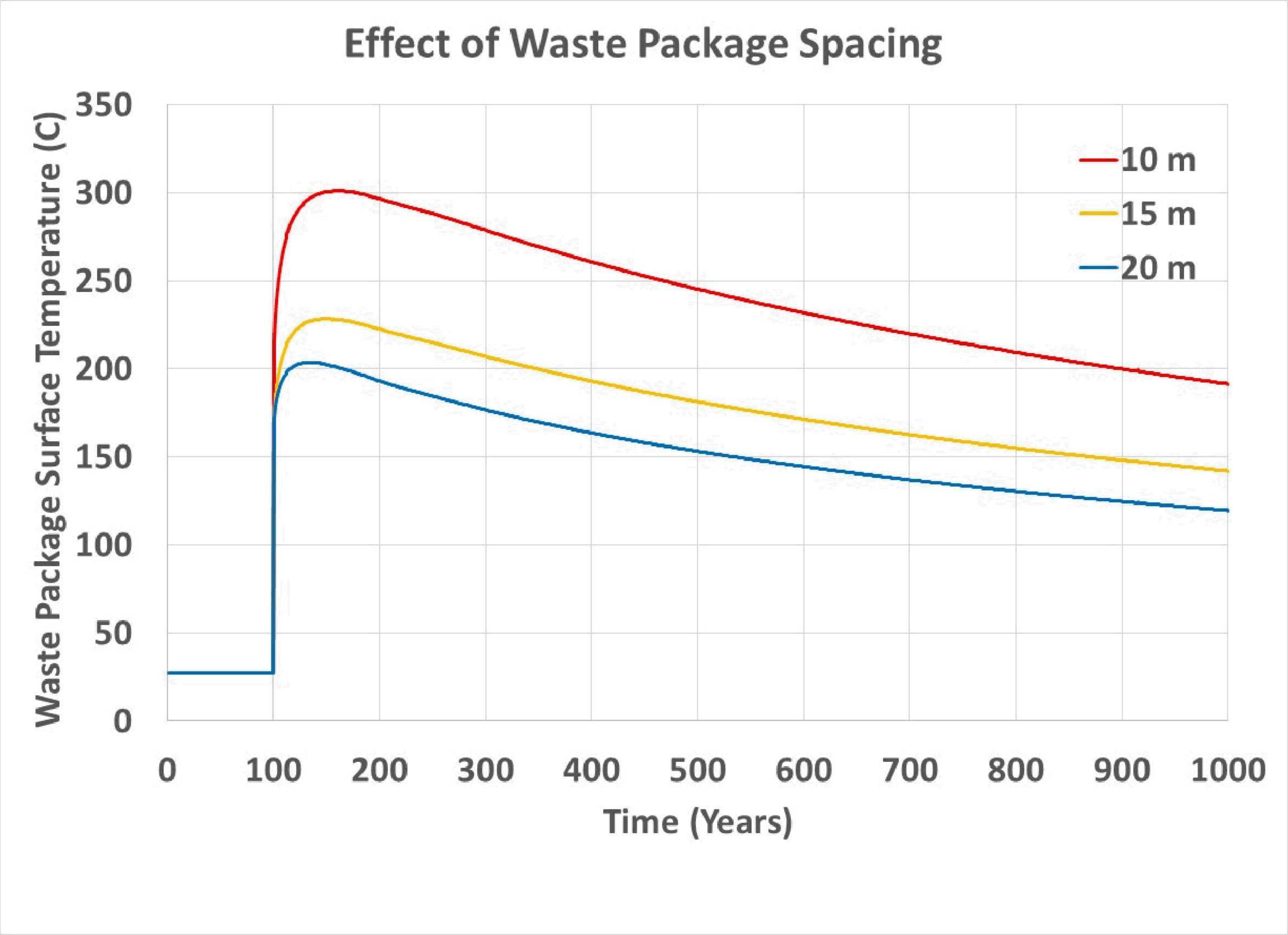
Results of Thermal Simulations: Surface Storage Times



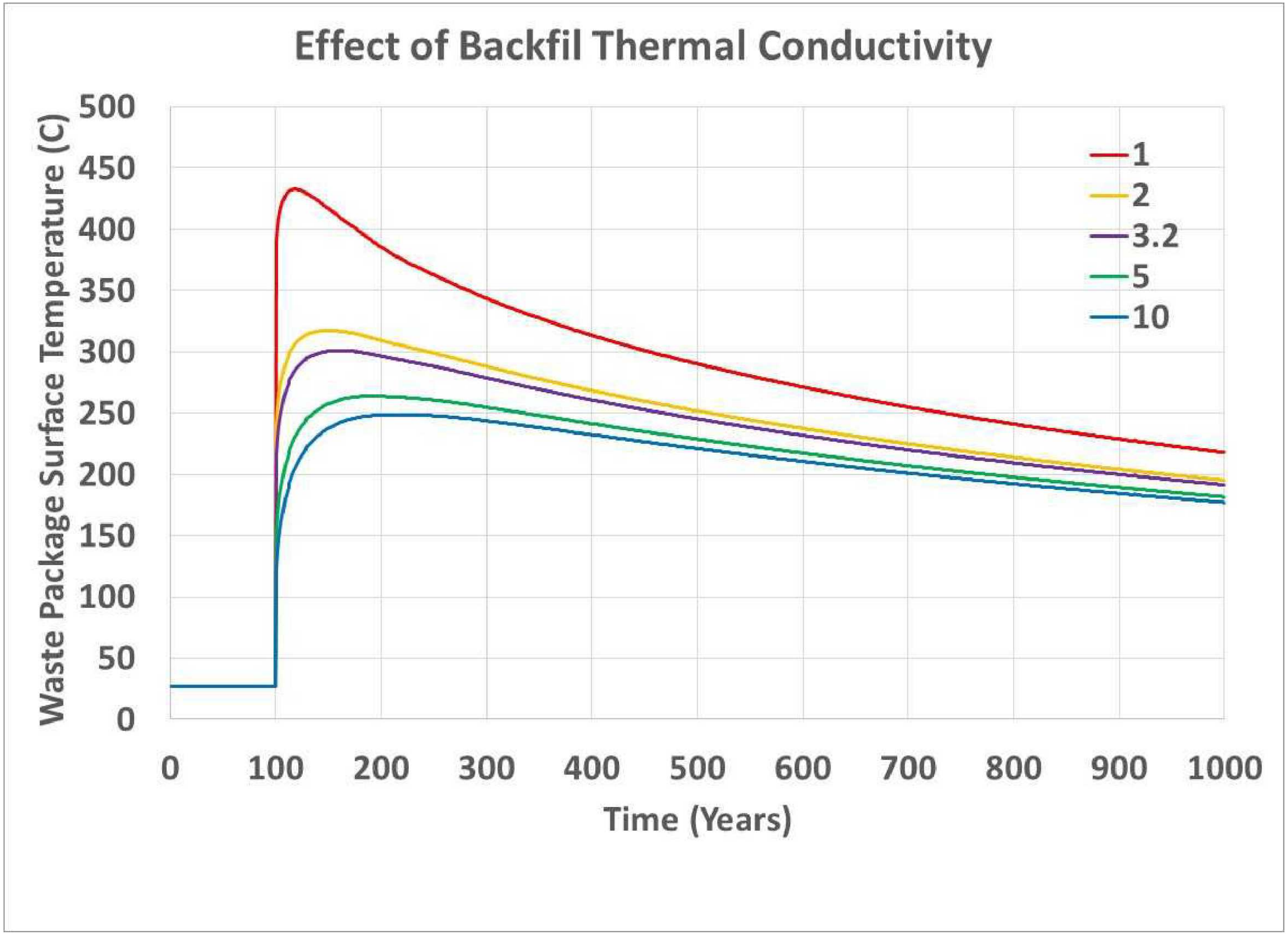
Results of Thermal Simulations: Drift Spacing



Results of Thermal Simulations: Waste Package Spacing



Results of Thermal Simulations: Crushed Salt Thermal Conductivity



Conclusions

- Presented results of TM and thermal-only modeling for disposal of DPCs in a salt repository.
- Direct disposal of DPCs would result in high thermal loads.
- The high thermal conductivity of intact salt helps to reduce peak temperatures.
- The predicted results showed that a combination of a larger repository foot print, a longer surface storage time and an engineered backfill would be required to control peak temperatures.

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