An Abstracted Model for Estimating Temperature and Relative Humidity in the Potential Repository at Yucca Mountain

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Outline

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Objective

- Assess temperature and relative humidity at waste package surfaces in a potential high-level waste repository
- Account for parametric uncertainties
- Assess effects of drift-degradation on waste package surface temperature

Background

- Heat is generated by the radioactive decay of spent nuclear fuel disposed in waste packages emplaced in underground drifts
- Increased temperatures will potentially affect:
  - Distribution of water in the near-field
  - Initiation of localized corrosion
  - Pore water chemistry
  - Radioactive waste dissolution
  - Mechanical properties of rocks
  - Enhancement of microbial processes

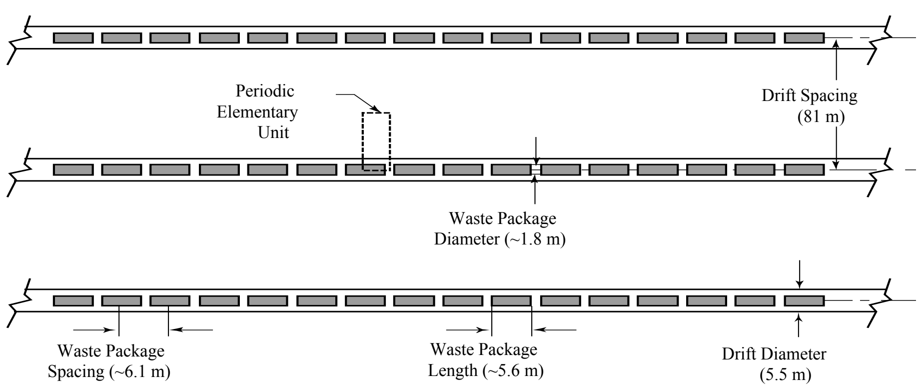
Model Abstraction

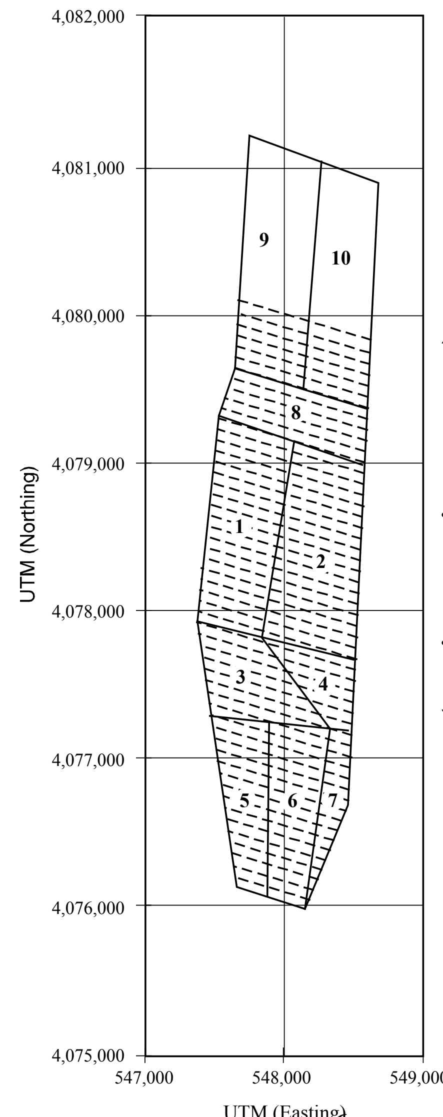
Abstracted model

- Needed because estimating temperatures in a probabilistic framework may require a large number of computer runs
- Needs to capture significant features, events and processes
- Usually requires uncoupling of the thermal and hydrological processes

Abstracted Model - Scales

- Heat transfer model consists of two parts:
  - Mountain scale
  - Drift scale
- Temperature is estimated at the drift wall at the center of each subarea
- Temperatures and relative humidity are estimated at the waste package surface





Repository Layout

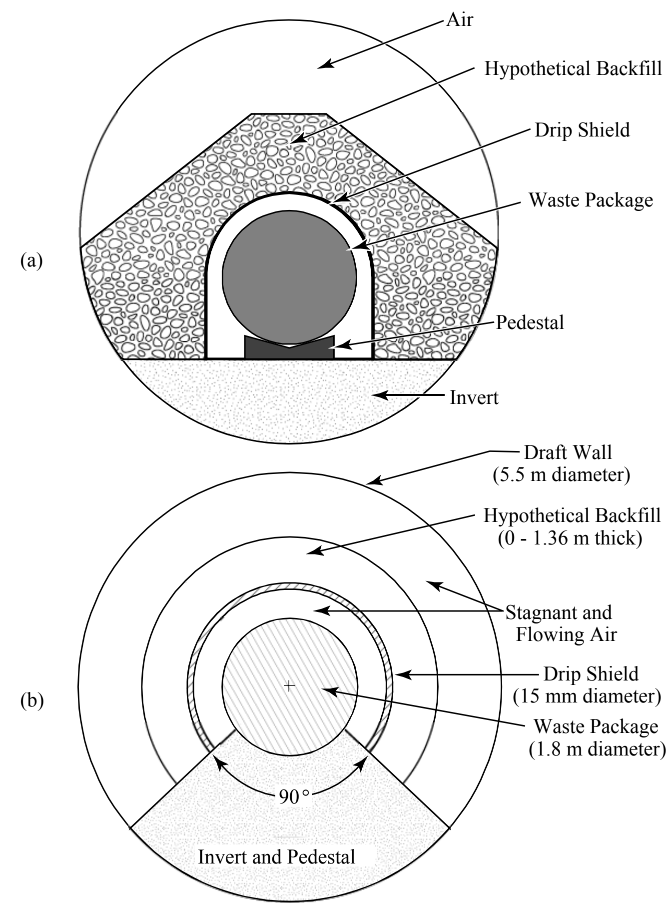
(Units are in meters)

Abstracted Model - Mountain Scale

- Estimates the repository-horizon rock temperature
  - Center of each subarea
  - At the drift wall
- Semi-analytic transient heat conduction model
- Drifts are represented as heat sources
- Assumptions
  - Uniform thermal properties and uniform heat loading at the repository level
  - Two-dimensional planar sources to represent the heat output in each drift at the repository level
  - Drifts are considered as heat sources though the model permits considering each waste package as a heat source
  - The ground surface is at a constant temperature and is not affected by climate change
  - No sharp increase in temperature along the drift

Abstracted Model - Drift Scale

- Estimate the waste package surface temperature from the rock temperature
- Use quasi-steady state assumption
- Represent in-drift heat transfer using a thermal network model that incorporates the details of the drift (drip shield, invert, air gaps, and potential backfill)
- Include heat transfer modes of conduction, convection, and radiation



$$Q_{wp} = G_{tot}\left(T_{wp} - T_{rock}\right)$$

$$G_{tot} = G_{cond,floor} + \left[\frac{1}{G_{rad1} + G_{conv1}} + \frac{1}{G_{cond,bfds}} + \frac{1}{G_{rad2} + G_{conv2}}\right]^{-1}$$

Abstracted Model- Drift Scale (continued)

- Relative humidity is defined here as the ratio of the saturated vapor pressure at drift wall to the saturated vapor pressure at the waste package surface
- Saturated vapor pressure is computed using the standard thermodynamic equation relating vapor pressure to temperature

$$\mathrm{RH} = \frac{P_{\mathrm{v}}\left[\min\left(T_{\mathrm{b}}, T_{\mathrm{rock}}\right)\right]}{P_{\mathrm{v}}\left(T_{\mathrm{wp}}\right)}$$

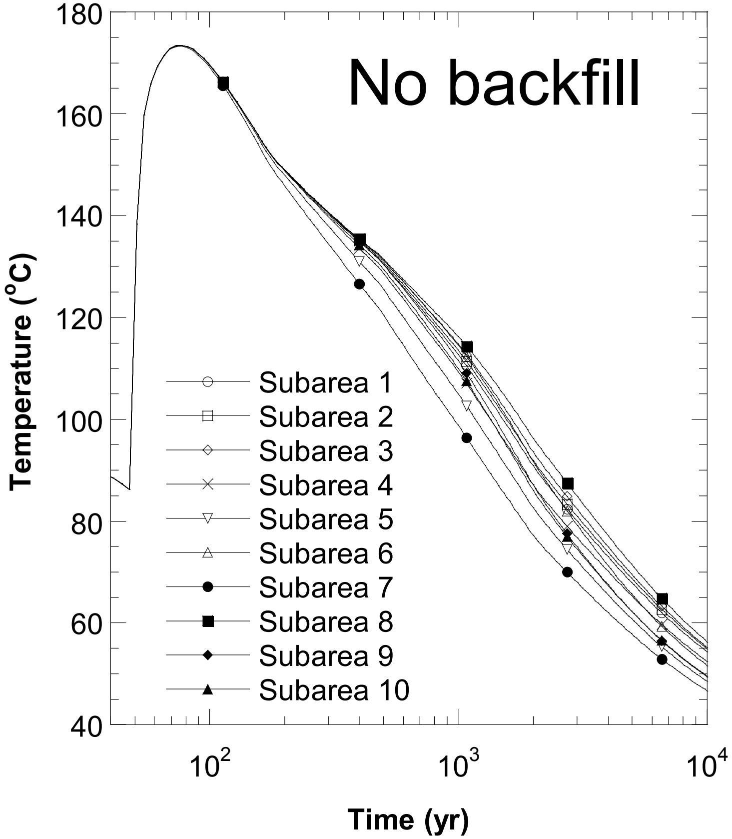
P_v — vapor pressure as a function of temperature [Pa]
min (T_b, T_{rock}) — minimum of T_b or T_{rock}
T_b — boiling point temperature
T_{rock} — drift wall temperature [K]
T_{wp} — waste package temperature [K]

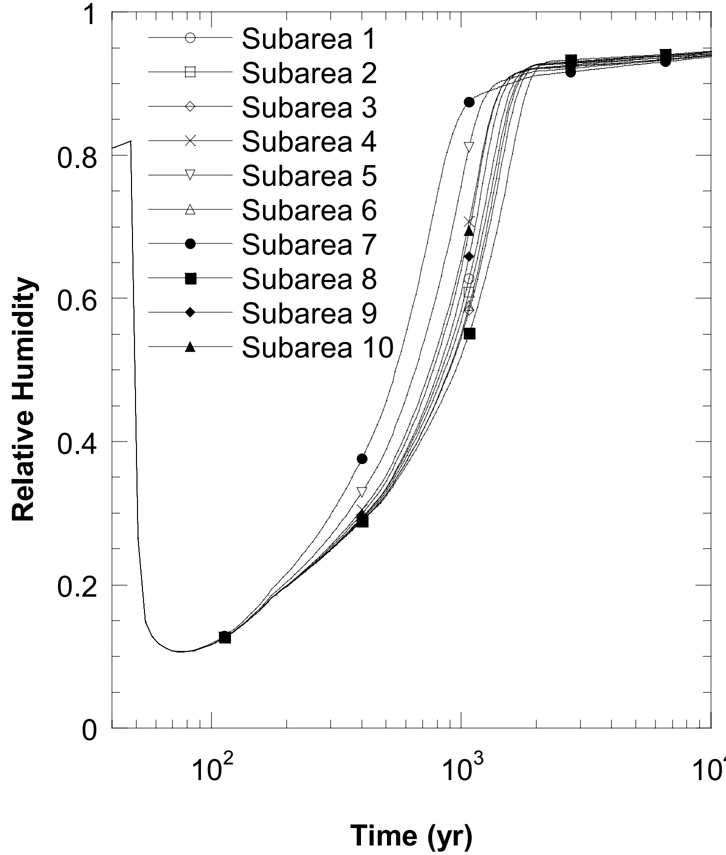
Parameters for Determining Repository Scale and Drift-scale Heat Transfer

Parameter	Value
Emplacement drift spacing	81 m
Waste package spacing along emplacement drift	6.14 m
Total waste emplaced in repository	70,040 MTU
Waste package payload	7.89 MTU
Number of equivalent WPs	8,877
Age of waste	26 yr
Ambient repository temperature	20 °C
Mass density of Yucca Mountain rock	2,580 kg/m^3
Specific heat of Yucca Mountain rock	840 J/(kg-K)
Thermal conductivity of Yucca Mountain rock (sampled)	1.34-1.75 W/(m-°C)
Emissivity of drift wall	0.8
Emissivity of drip shield	0.63
Emissivity of WP	0.87
Thermal conductivity of floor	0.6 W/(m-°C)
Effective thermal conductivity (with natural convection)	0.9 W/(m-°C)
Factor for ventilation heat losses, f_v	0.70
Time of repository closure	50 yr
Effective thermal conductivity of the hypothetical backfill	0.27 W/(m-°C)

Example Results

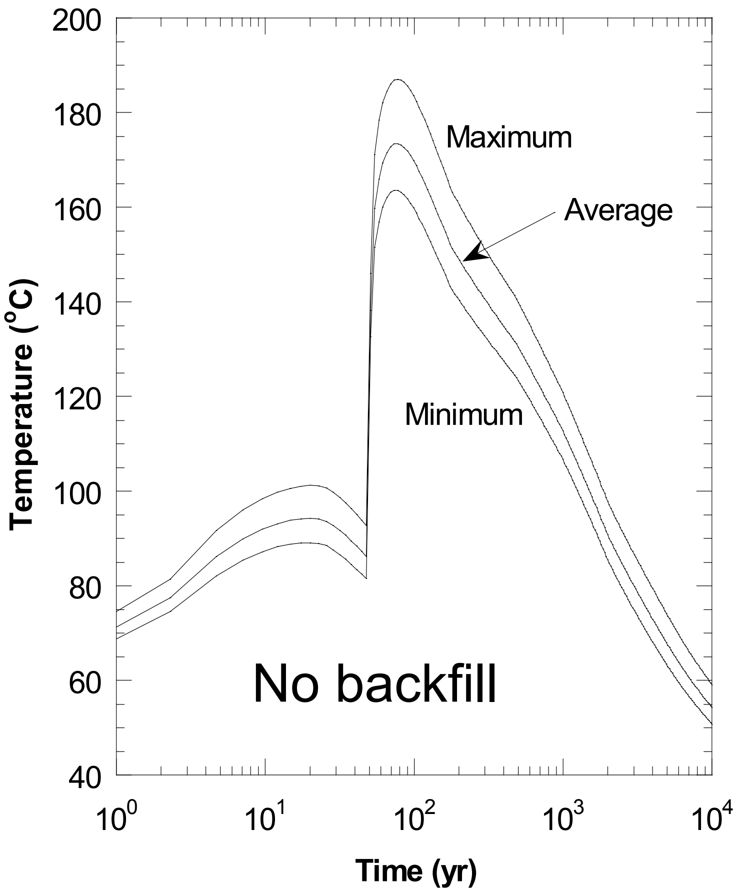
Subarea-to-subarea variation in waste package surface temperature and relative humidity (averaged for 350 Monte Carlo realizations for each subarea)





Example Results (continued)

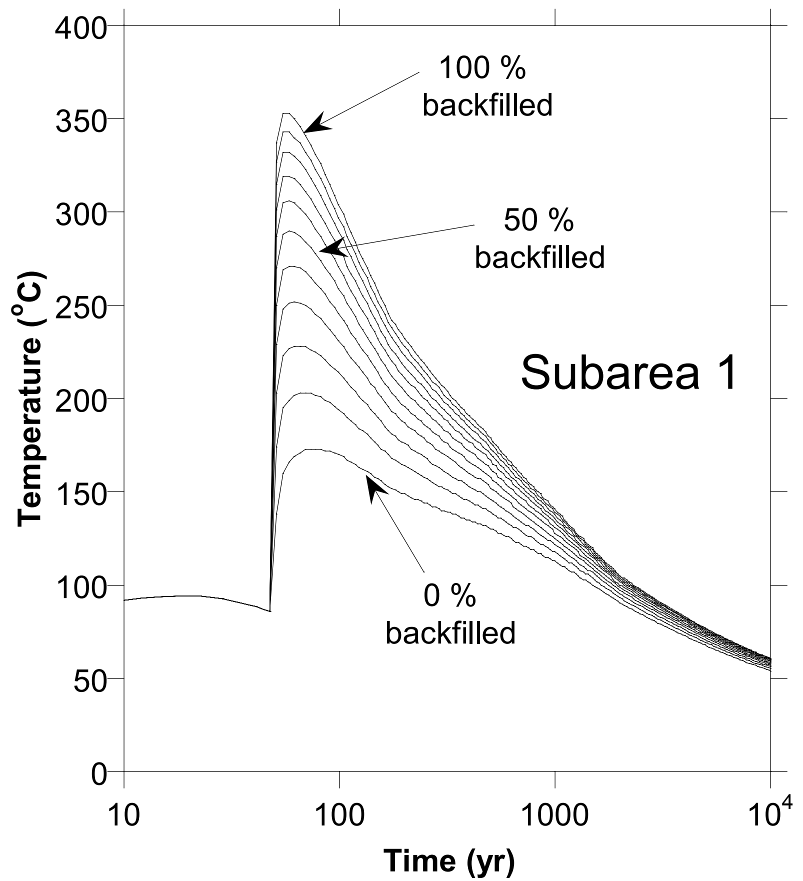
Maximum, minimum, and average waste package surface temperatures in subarea 1 from 350 Monte Carlo realizations



Example Results (continued)

- Parameter Values
  - Maximum hypothetical thickness: 100 percent backfilled is 1.36 m (the radial distance between the outer wall of the drip shield and the drift wall)
  - Backfill thickness is constant with time
  - All other parameters set to their mean values
- For the 100 percent backfill case, a peak temperature of 353 °C occurs at 54.5 years.

With a hypothetical backfill



Conclusions

- Based on an abstracted model for estimating temperatures in a probabilistic system model requiring multiple Monte Carlo realizations.
  - The basecase (i.e., no backfill) waste package temperature near the center of the potential repository is approximately 165 °C on an average.
  - The waste package temperature remains above boiling for nearly 1,000 years even without the hypothetical backfill.

Conclusions (continued)

- The presence of a hypothetical backfill results in the peak waste package temperature for the fully backfilled condition approximately double that for the no-backfill condition.
- The time span for which the estimated temperature remains above boiling is much longer than in the no-backfill case.

- Future work will involve
  - A more accurate analysis of backfill on waste package temperature to include natural backfilling
  - Incorporation of cold-trap effect into the abstracted model if detailed calculations show it will have a significant influence on relative humidity along the drifts