U.S. Department of Energy
Office of Civilian Radioactive Waste Management

Evaluation of a Range of Operating Modes

Presented to:

Nuclear Waste Technical Review Board

Joint Meeting of Performance Assessment and Repository Panels
Supplemental Science and Performance Analyses (SSPA)

Presented by:

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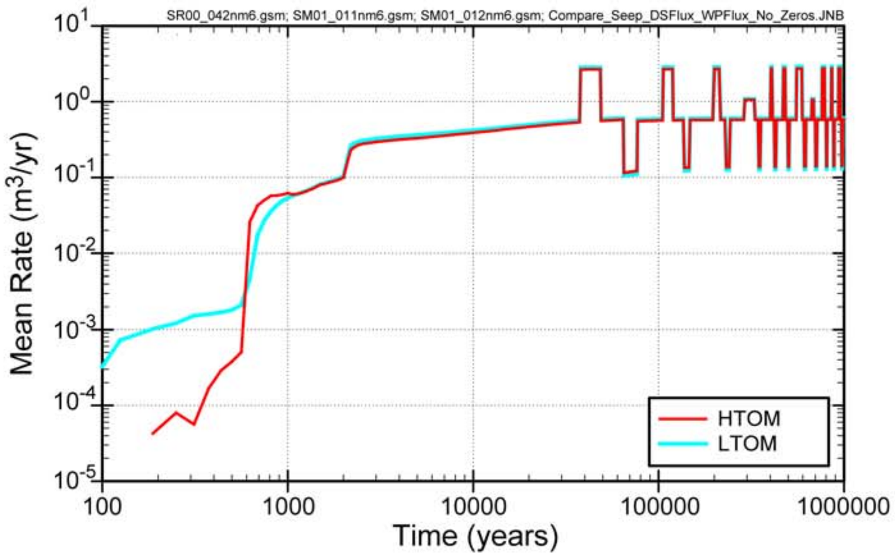
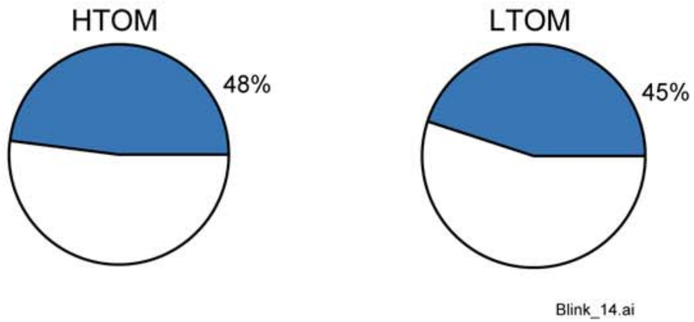
YUCCA MOUNTAIN PROJECT

Outline

- **Goal**
  - Synthesize higher- and lower-temperature operating modes (HTOM/LTOM) contrast based on process models
- **Subsystems**
  - Thermal seepage
  - In-drift thermal hydrology
  - Thermal-hydrologic-mechanical (THM) effects
  - Thermal-hydrologic-chemical (THC) effects, in-drift water and gas chemistry
  - Waste package (WP) corrosion
  - Water diversion in the engineered barrier system (EBS)
  - Waste form mobilization
  - EBS transport
  - Unsaturated zone (UZ) transport

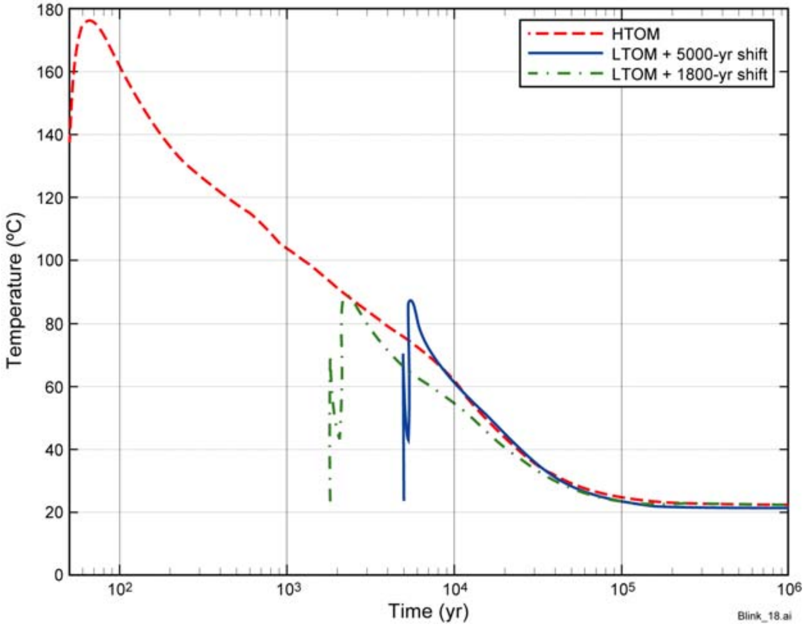
Thermal Seepage in TSPA





- **LTOM seepage**
  - **Total System Performance Assessment (TSPA) model ~ Ambient model**
- **HTOM seepage**
  - **Process model < TSPA model < Ambient model**

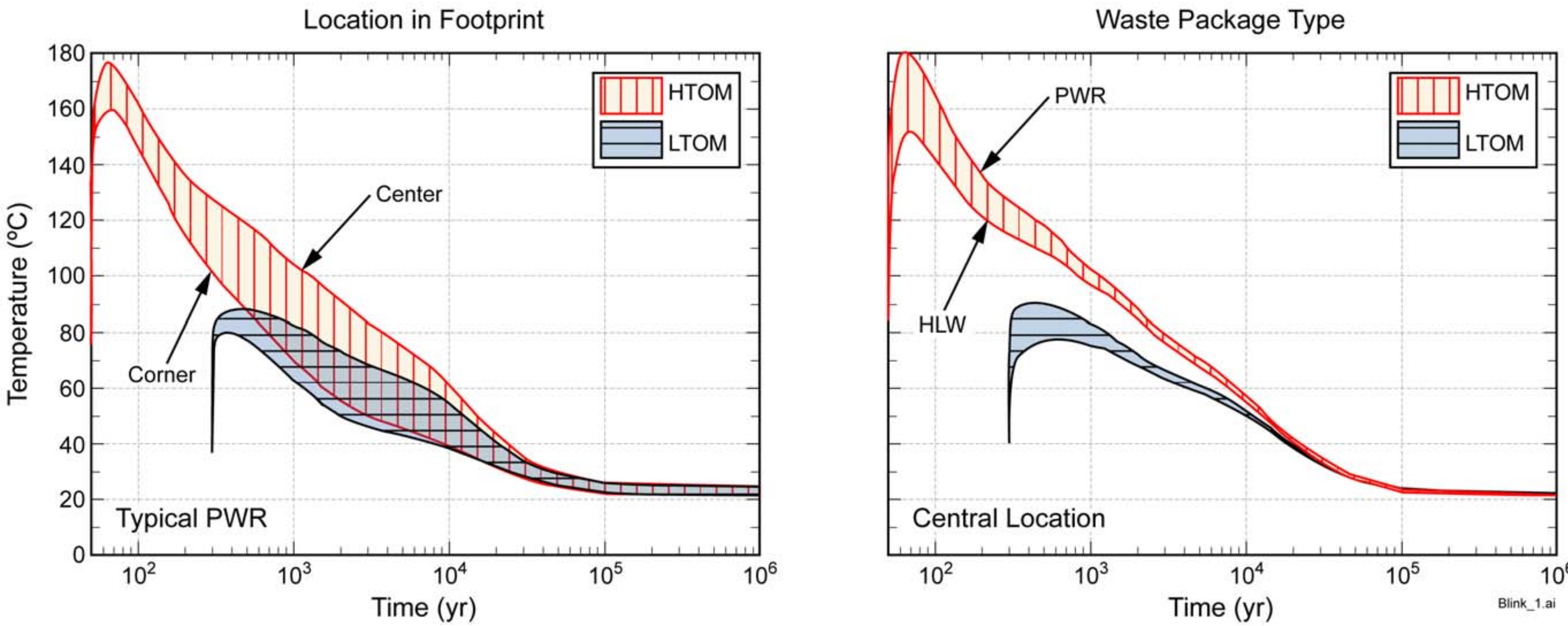
The LTOM Thermal History is Similar to the HTOM after a Few Thousand Years



- **HTOM models include the LTOM environments**
- **High temperature parts of the models could increase HTOM uncertainty compared to LTOM**

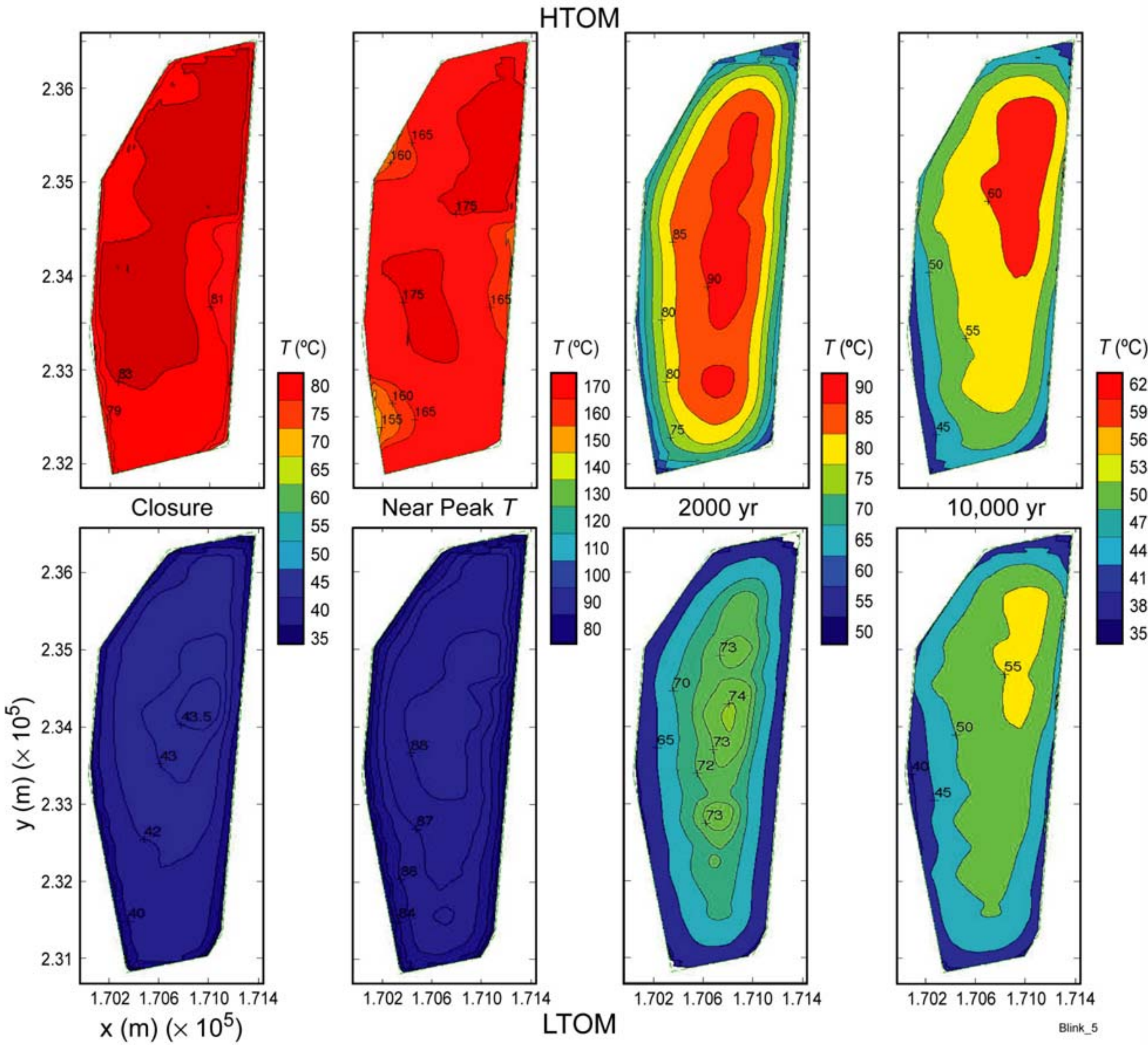
HTOM and LTOM performance are similar because the HTOM thermal pulse does not significantly affect the EBS or Natural Barrier System

WP Temperature Sensitivity to Location and WP Type



- **The variability range for location and WP type is ~20ºC**
- **The variability range for operating mode is ~90ºC**

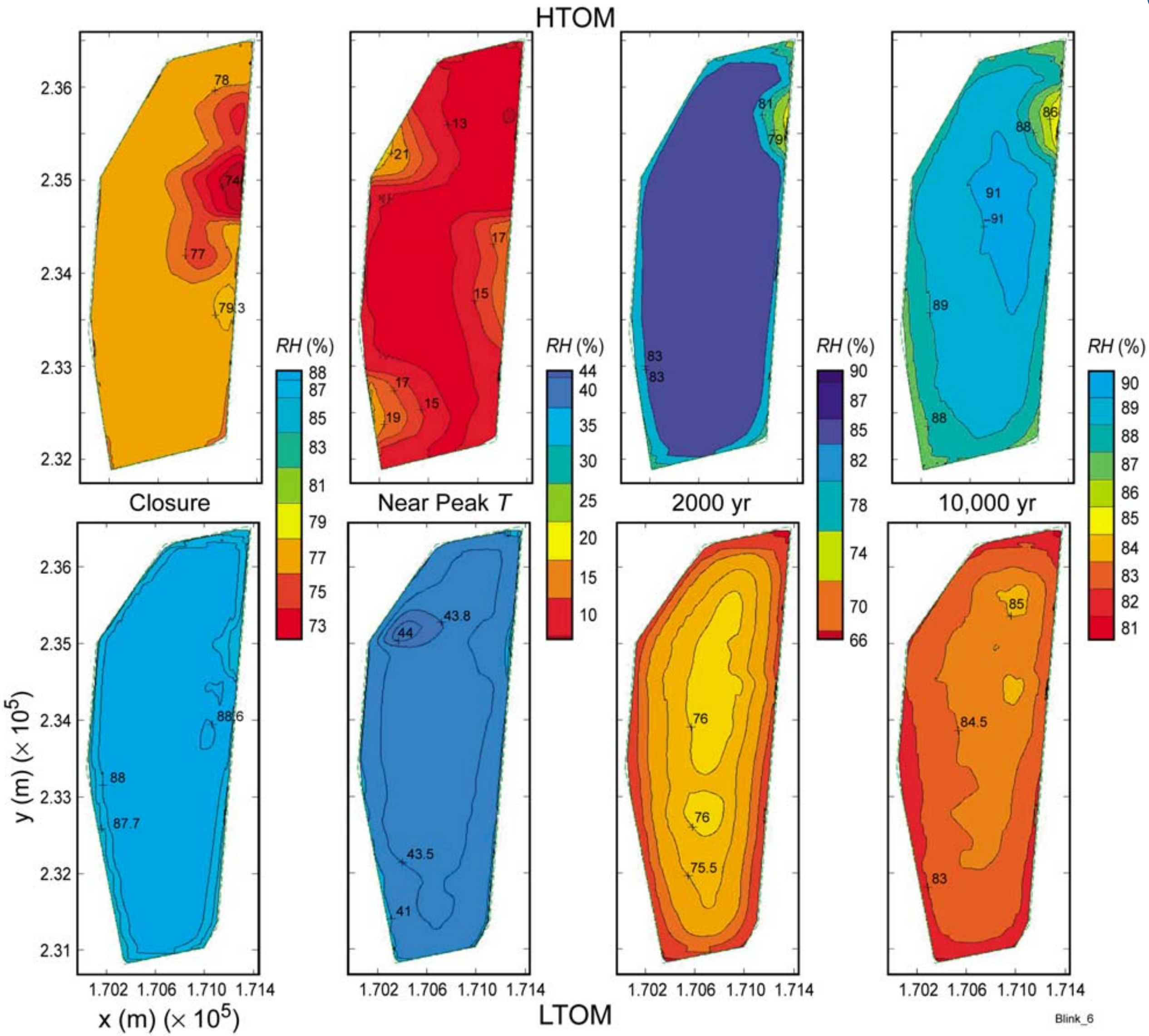
Typical PWR WP Temperature Sensitivity to Location



- Common color bar for each time period
- Similar distributions at 10,000 years, LTOM slightly cooler

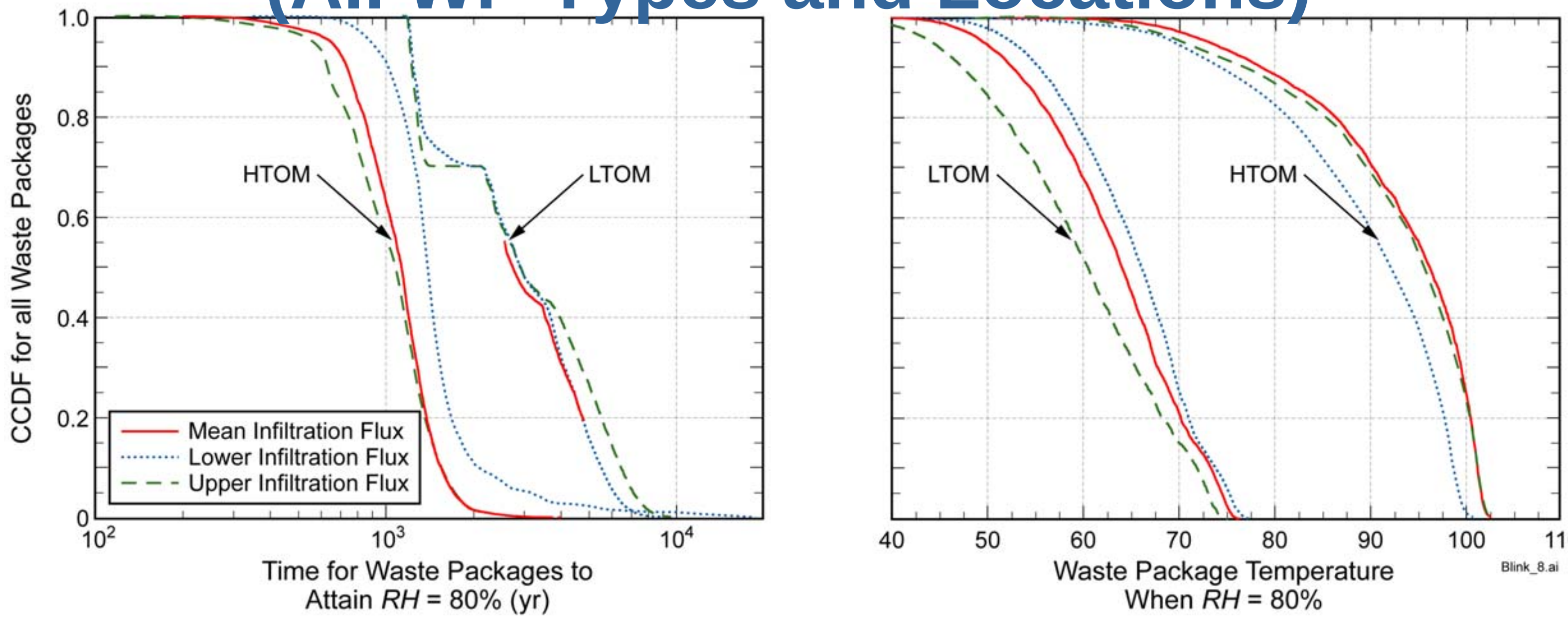
Spatial variability similar for HTOM and LTOM

Typical PWR WP Humidity Sensitivity to Location



- **Earlier two snapshots have drier HTOM**
  - **Earlier "real" time has higher WP heat**
  - **Near-field dryout**
- **Later two snapshots have drier LTOM**
  - **Larger EBS thermal gradient due to less effective thermal radiation at slightly lower temperature (T)**

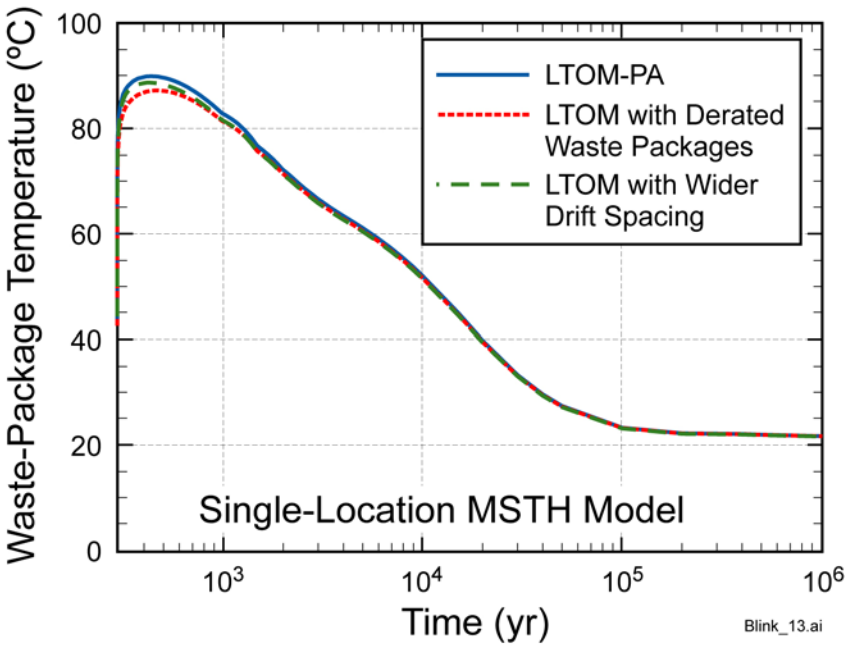
Sensitivity of WP Relative Humidity (RH) Infiltration Rate and Operating Mode
(All WP Types and Locations)



- **LTOM has higher temperature difference due to less effective radiation heat transfer**
- **RH depends on temperature difference between drift wall and WP because RH= P_{vap}/P_{sat} and P_{sat} is f(T)**

LTOM low RH is longer duration than HTOM

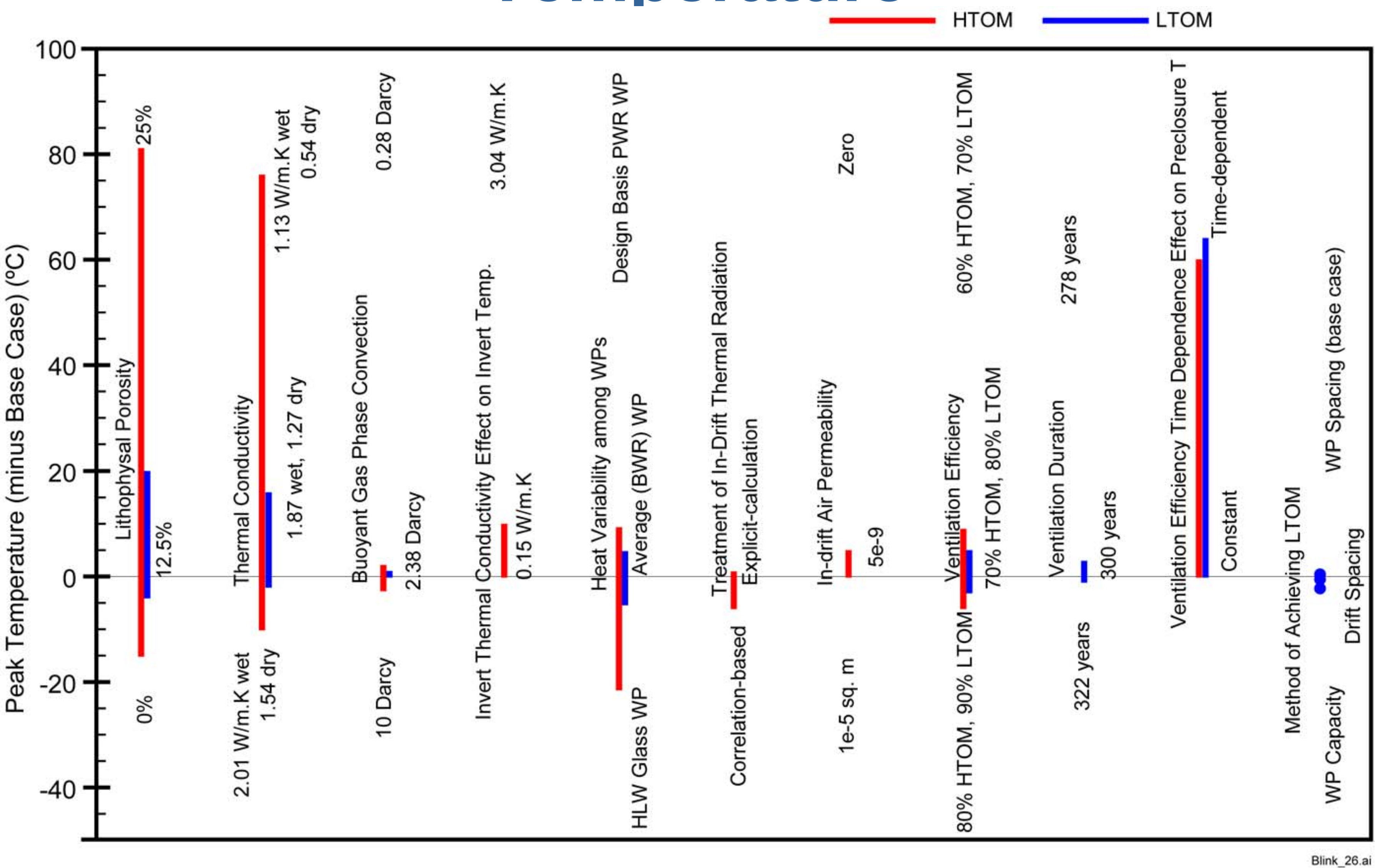
Three Lower-Temperature Operating Modes



- **Several design and operating mode configurations can achieve LTOM**
- **WP spacing, WP capacity, and drift spacing examples with same AML**
- **Peak T not strongly dependent on LTOM method, for a given AML**
- ***Other factors than T or dose, (such as uncertainty, worker safety or cost) could be important for LTOM method selection***

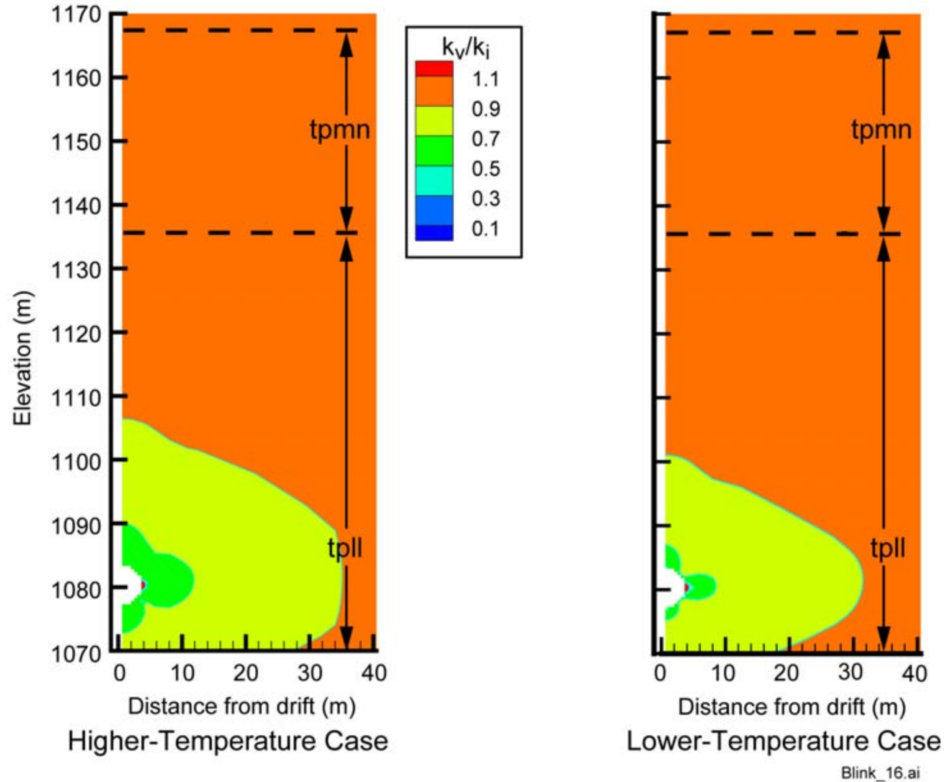
Performance assessment models are suitable for a variety of LTOM methods

Sensitivity of Peak Postclosure Temperature



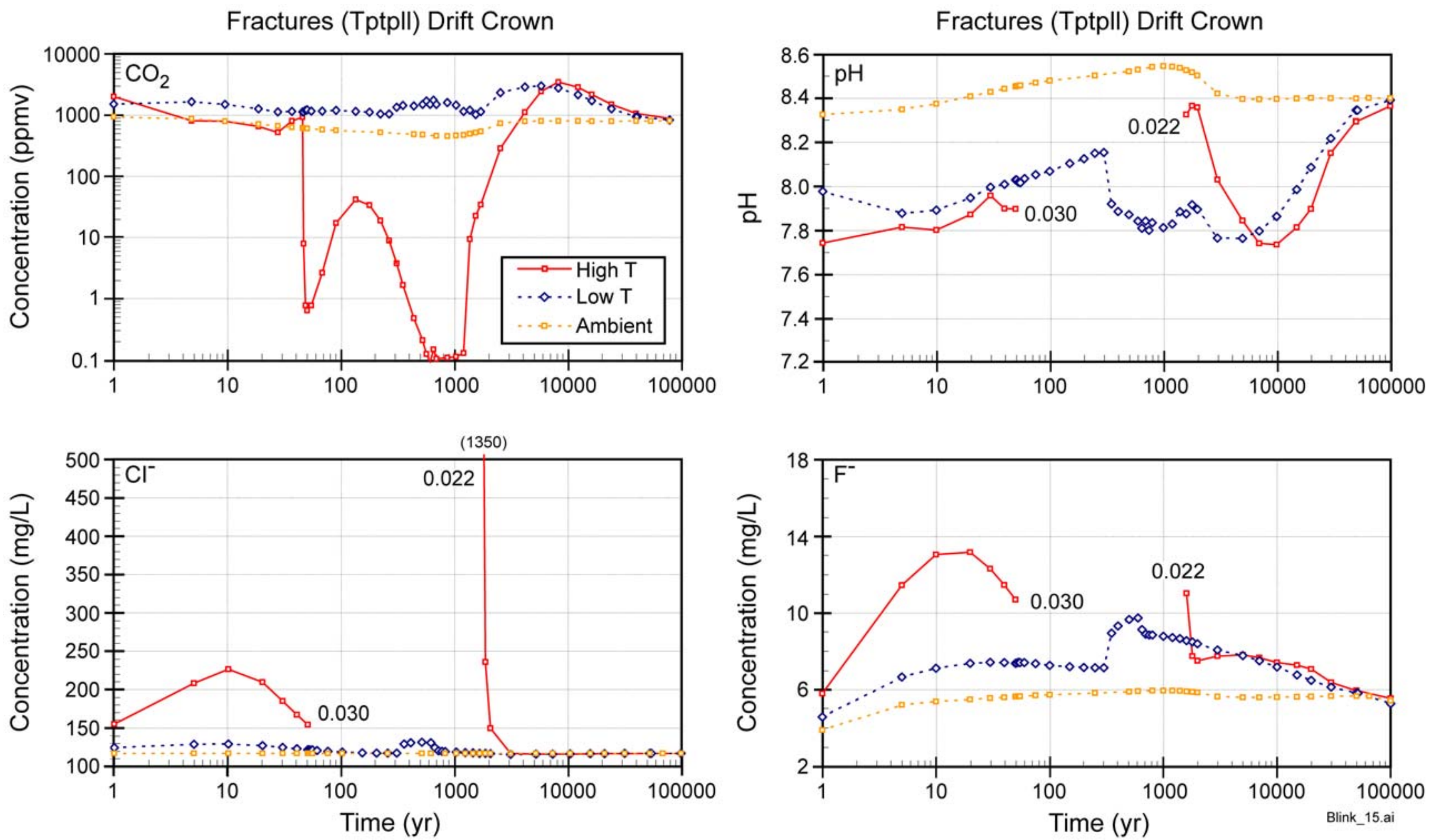
Thermal-Mechanical Caused Permeability Changes

- **At 10 years, both thermal cases show an overall decrease in permeability around the drift due to thermal stress induced by decay heat**
- **This decrease overcomes the initial excavation-induced permeability increases, except possibly in areas very close to the crown of the drift**



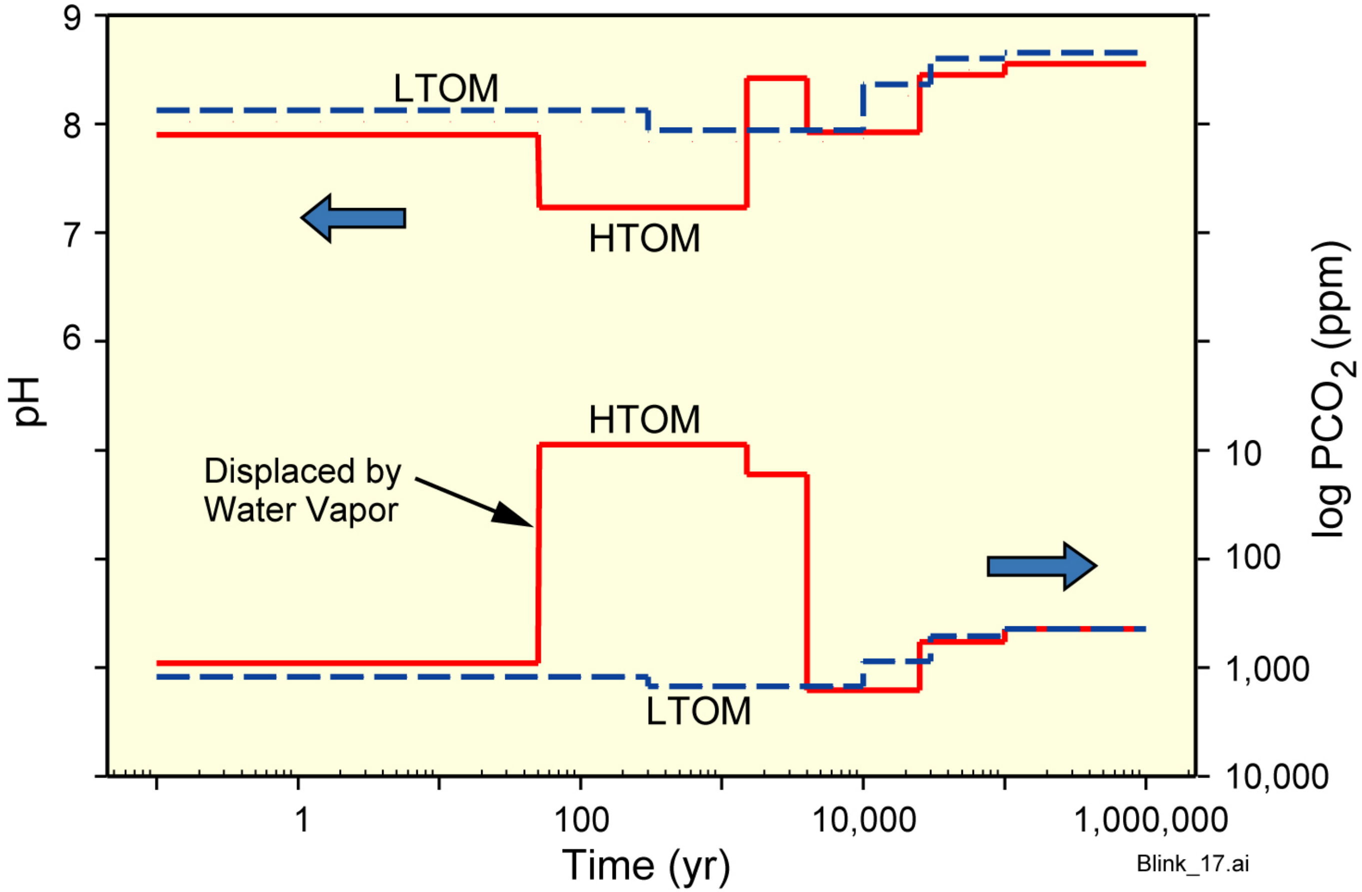
LTOM and HTOM are similar

Seepage Water Chemistry



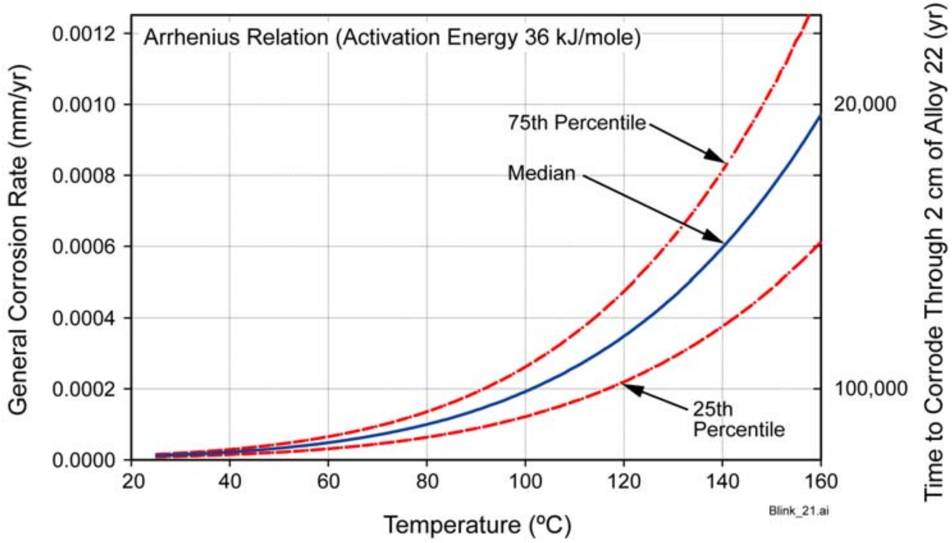
LTOM and HTOM are similar after 2000 yr

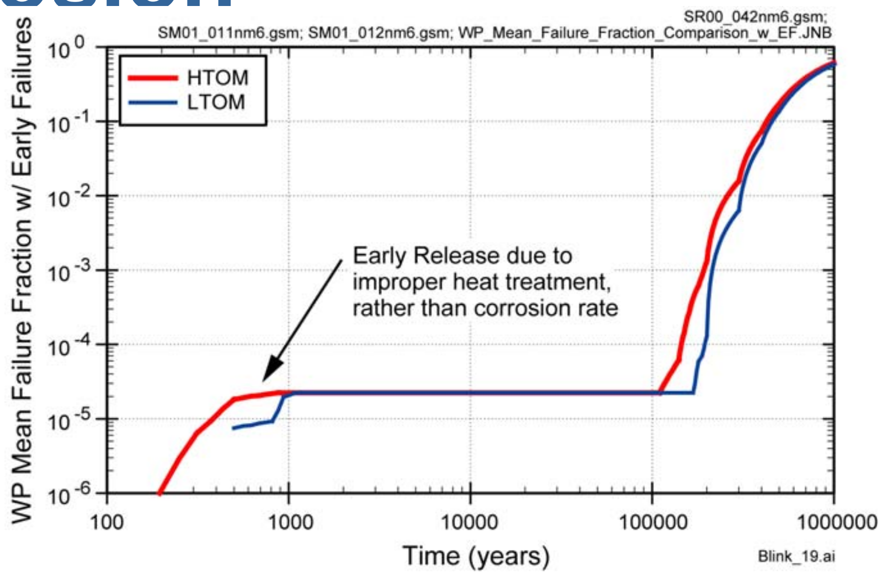
In-Drift Water and Gas Chemistry
(after temporal abstraction, prior to gas-liquid equilibration)



HTOM and LTOM are similar after a few 1000 yrs

WP Corrosion

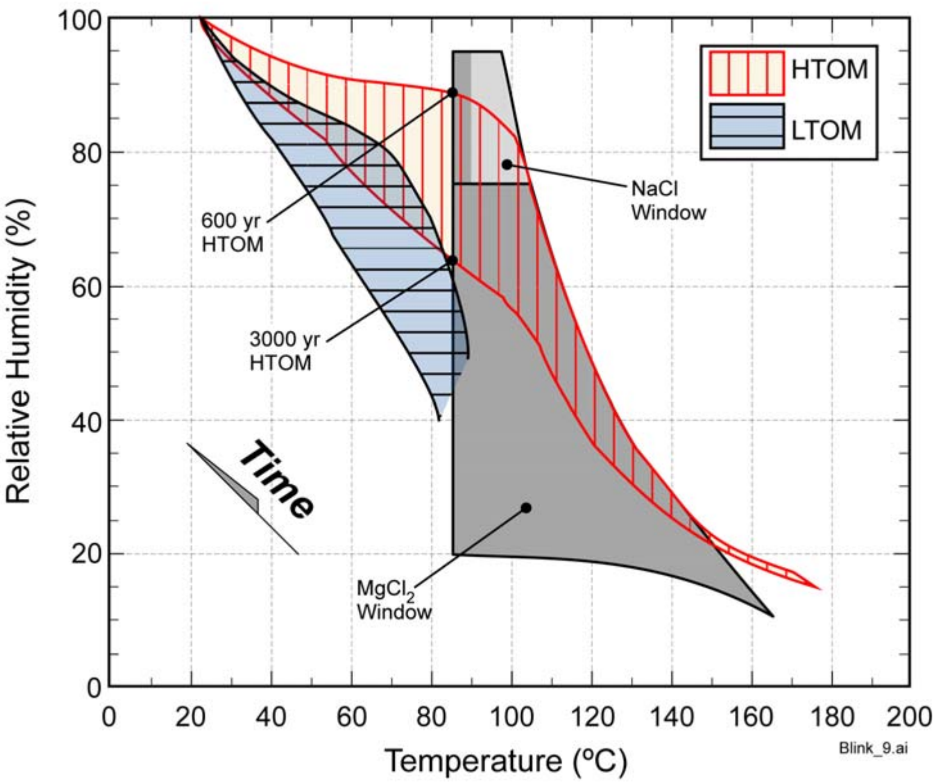




- **Potentiostatic polarization measurements determined T-dependence**
  - **pH 2.75 and 7.75**
  - **LiCl, Na_2SO_4, $NaNO_3$ aqueous environment**
  - **Chloride to (Sulfate + Nitrate) ratios 10:1 and 100:1**
- **Includes general corrosion, local corrosion, and stress corrosion cracking**
- **General corrosion mode increased**
  - **by 1.0 to 2.0 for MIC**
  - **by 1.0 to 2.5 for aging (at closure weld)**

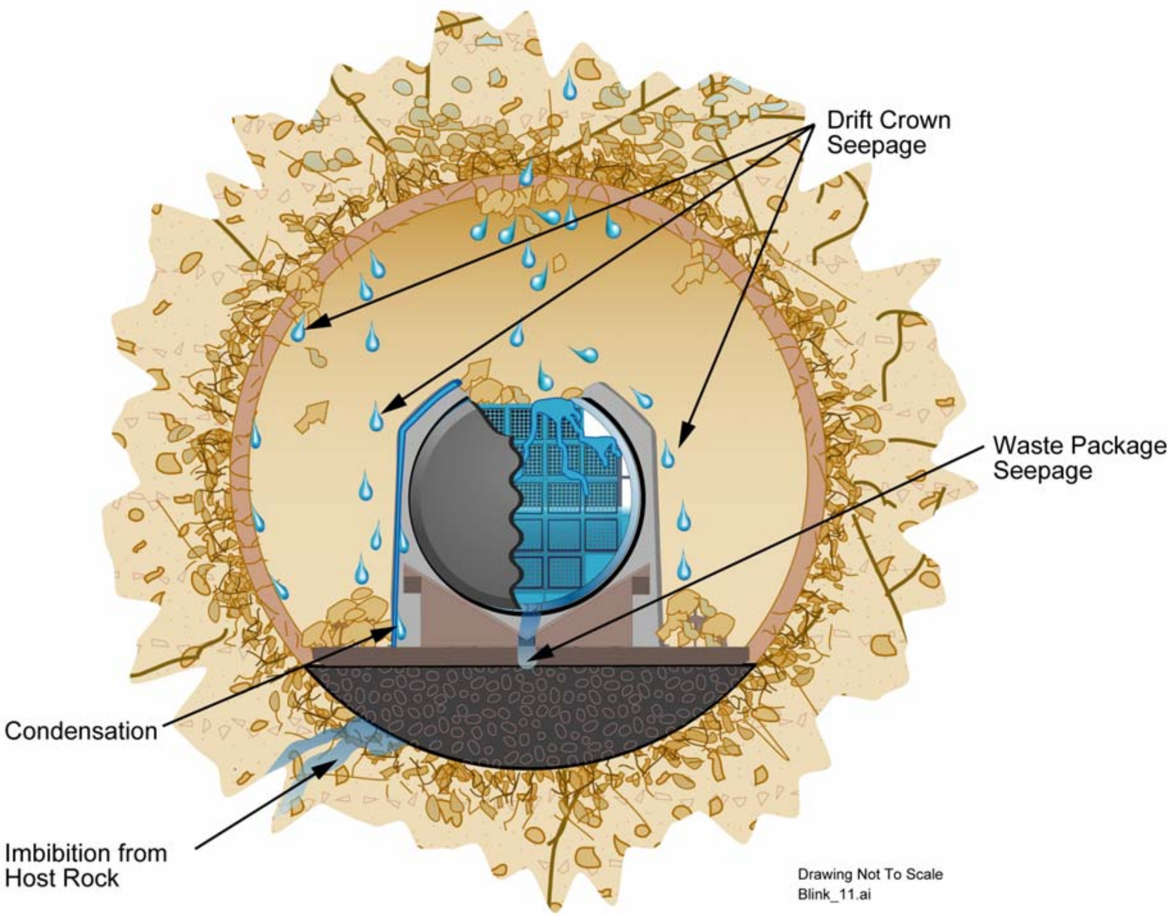
LTOM and HTOM are similar

WP Temperature-Humidity Trajectories and the Crevice Corrosion Initiation Window of Susceptibility



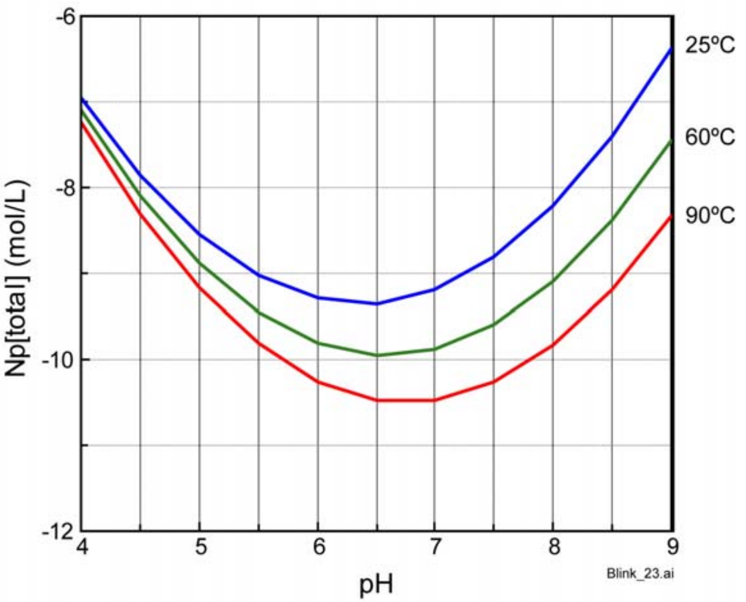
- **Crevice corrosion initiates by breaching the passive film**
- **The process model crevice corrosion initiation window includes T, [Cl-] and pH**
  - **The pH dependence dominates T and [Cl-]**
- **The TSPA crevice corrosion initiation is based on pH**
- ***Both LTOM and HTOM avoid crevice corrosion***
  - **LTOM: Temperature criterion**
  - **HTOM: Chemistry (pH) criterion**

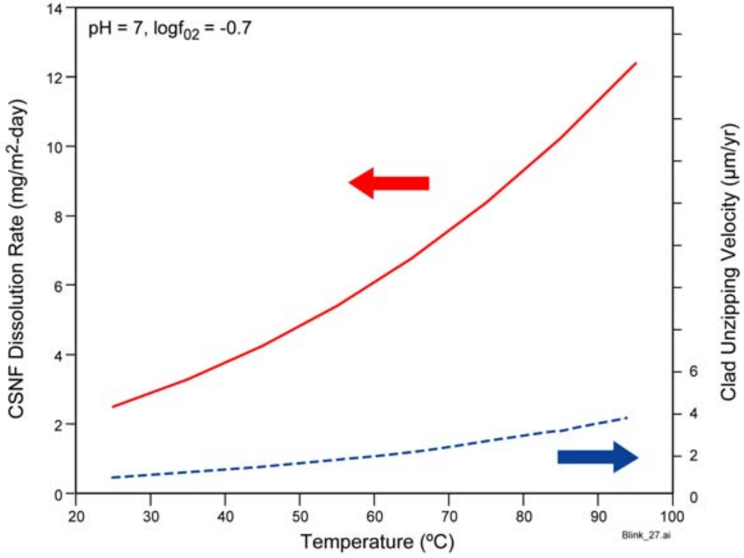
Water Diversion in EBS



- **Model geometry realism was improved**
- **Not sensitive to operating mode**

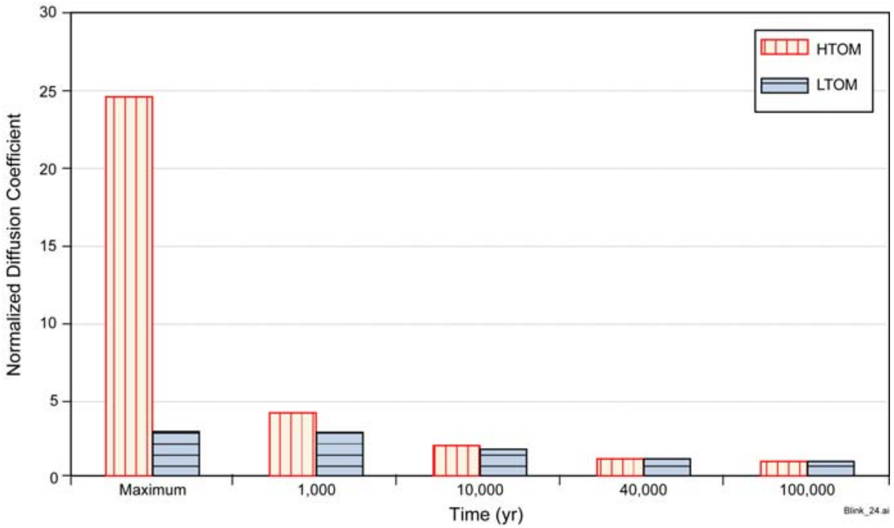
Waste Form Mobilization

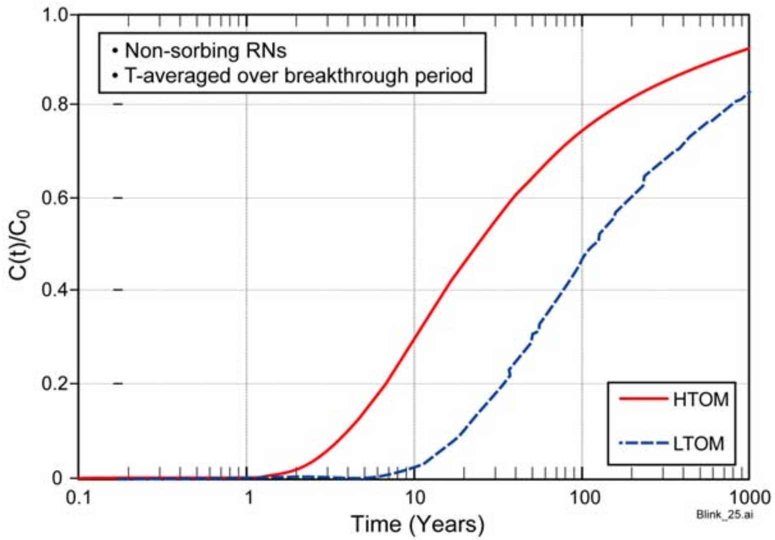




- **Other factors had little or no T-dependence**
  - **In-WP pH: used 25ºC-dominated database**
  - **Lower Pu solubility at high-T still too uncertain for SSPA model**
  - **In-WP diffusion coefficient not strongly T-dependent**
  - **In-WP sorption T-dependence uncertain, higher sorption at higher-T is likely**
  - **Clad Creep is T-dependent, but negligible total creep**
  - **Little T-dependence for colloids**

Engineered Barrier System Transport





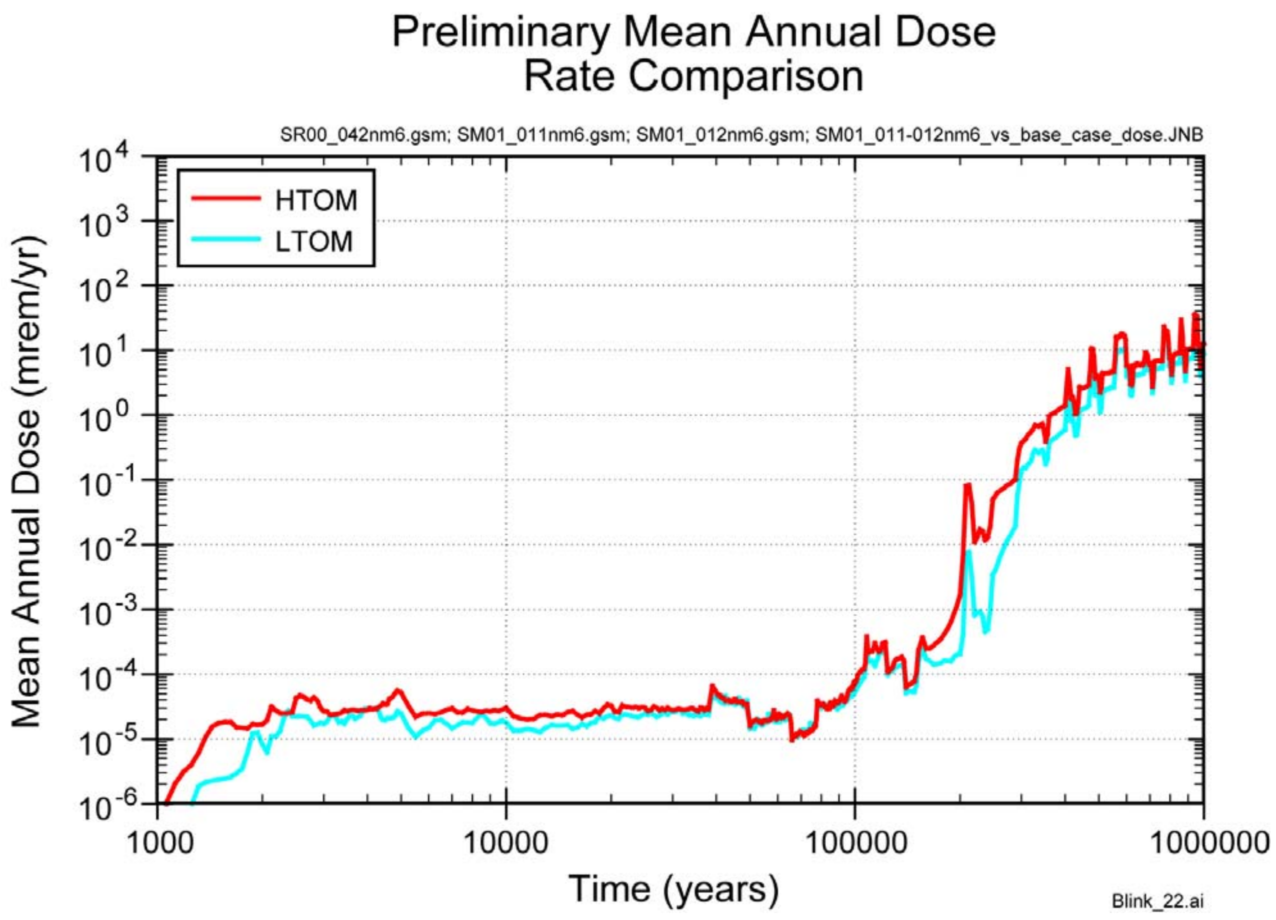
- **Parameters depend on T**
  - **Diffusion coefficient is f(T, S_{invert})**
  - **Absorption of water vapor (condensate thickness)**
  - **Evaporation/condensation fluxes**

Negligible difference between HTOM and LTOM because very few WPs fail when temperatures are different

Unsaturated Zone Transport

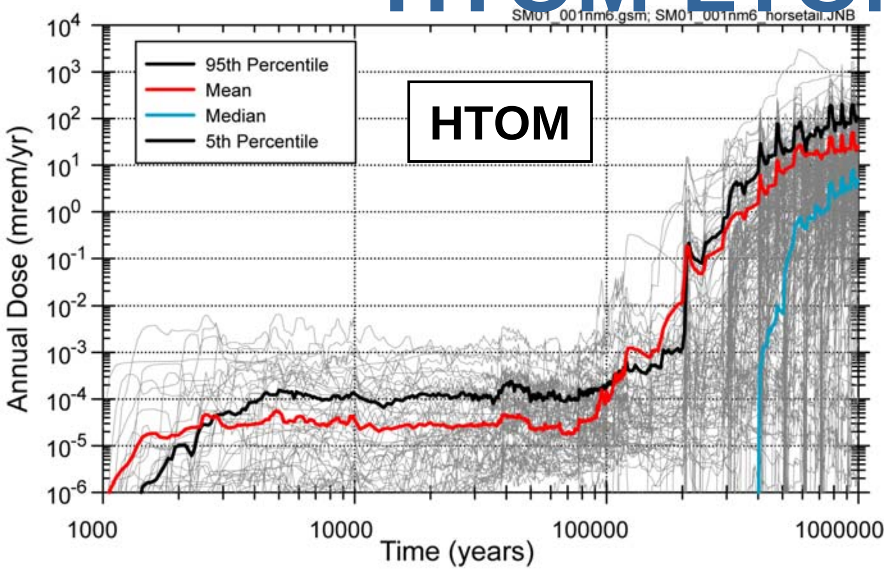
- Calico Hills peak temperature (~75ºC HTOM)
  - Is not high enough
  - For long enough
  - For significant zeolite alteration which could change flow patterns or sorption

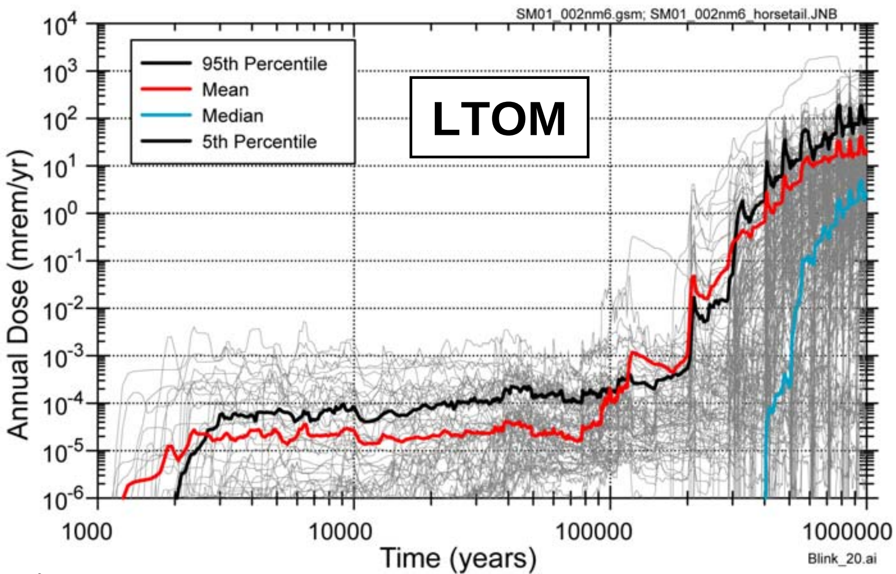
Total Dose



Because most WP failures are well beyond the thermal pulse, HTOM and LTOM mean dose rates are similar

Total Dose Uncertainty and HTOM-LTOM Summary

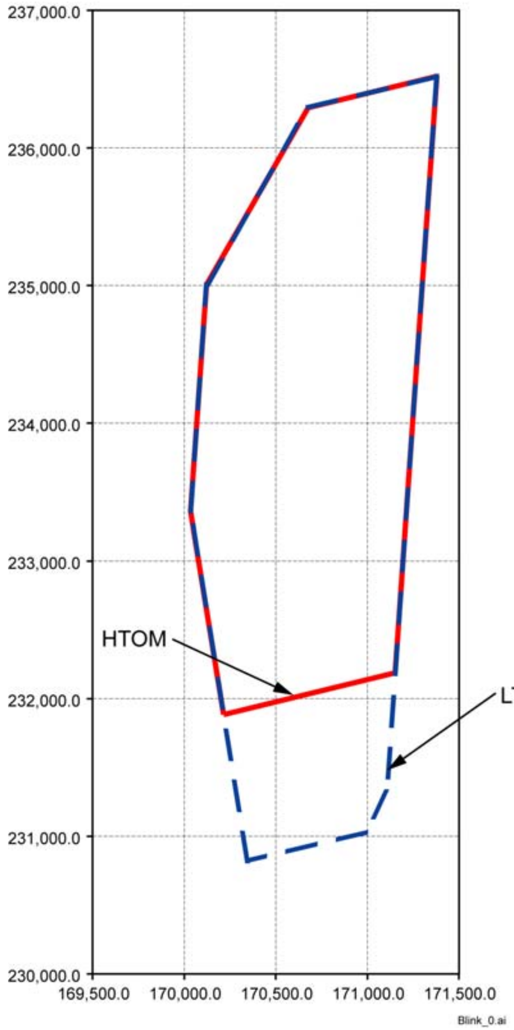




- ***The TSPA uncertainty ranges for HTOM and LTOM are similar***
- ***TSPA models apply to both LTOM and HTOM***
- **Process level models evaluate subsystem uncertainties, which in some cases, are propagated in TSPA abstractions**

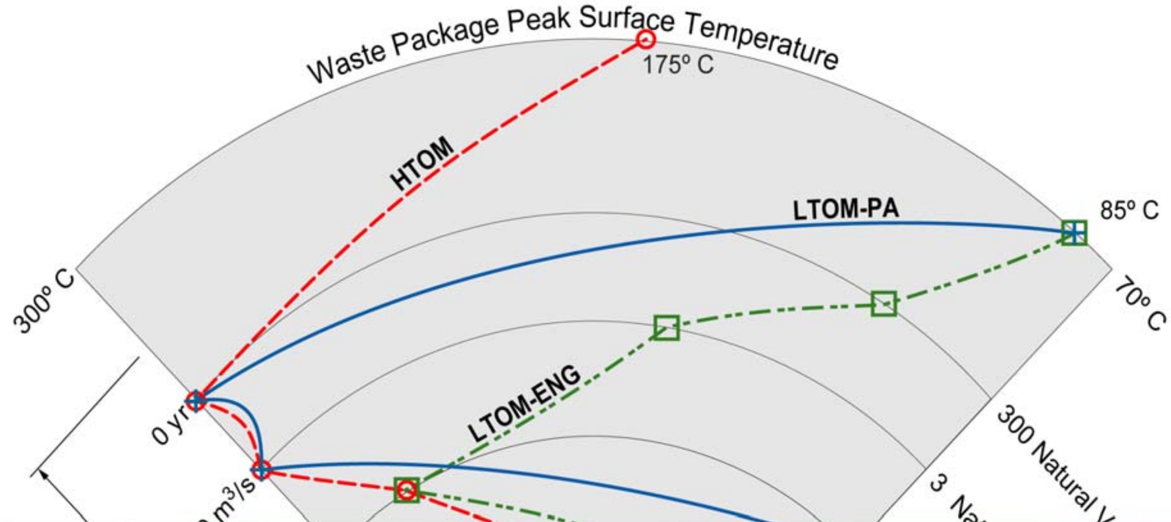
Backup

HTOM and LTOM Repository Footprints for TH Calculations



- **The S&ER footprint was similar to the HTOM, but did not extend as far to the North**

Design and Operating Mode Parameters Used to Meet Peak Waste Package Temperature Goals



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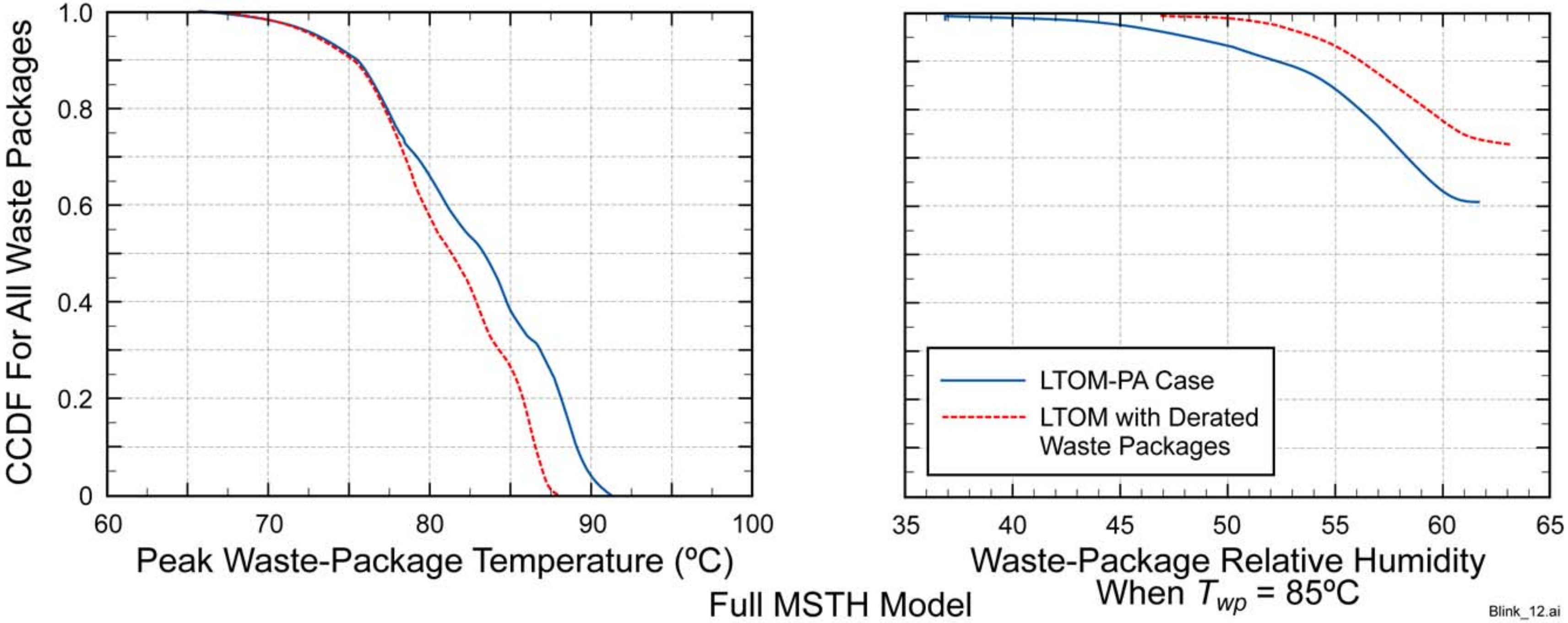
Two Lower-Temperature Operating Modes



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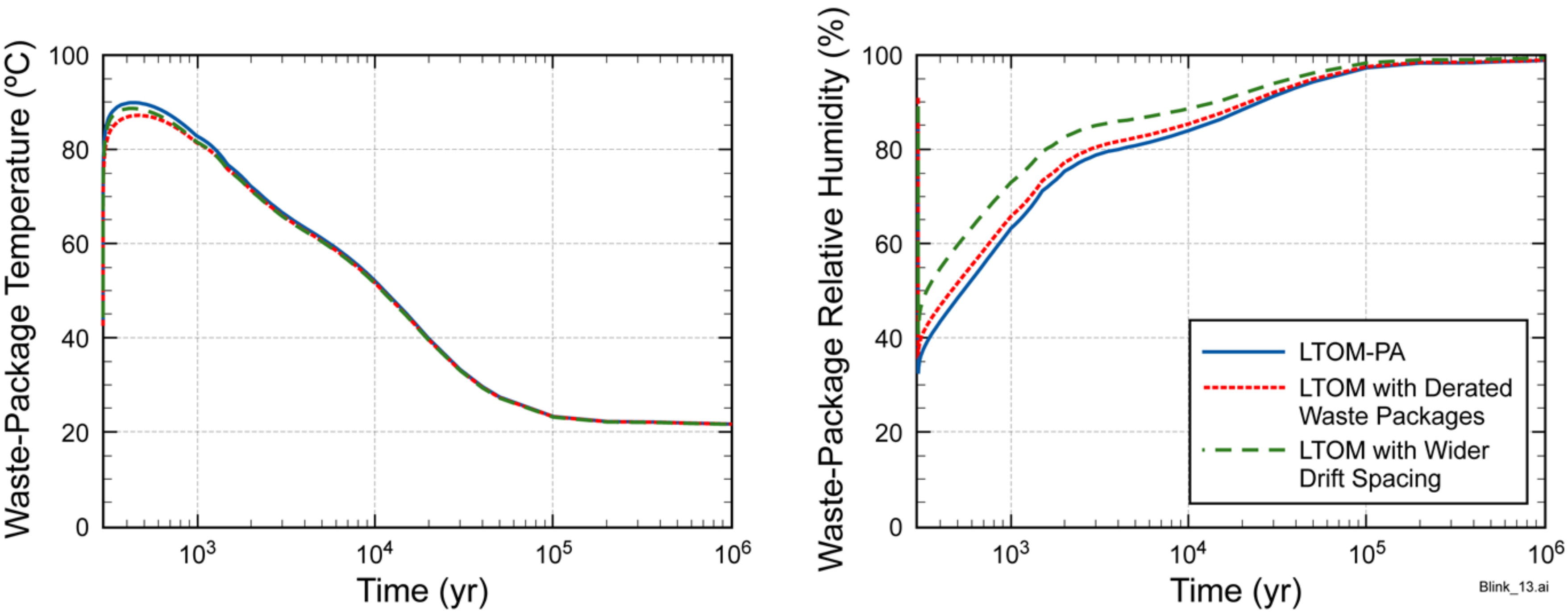

Single-Location MSTH Model