U.S. Department of Energy

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

# Rate of Water Flow Out of Repository Drifts Over Time

Presented to:
**Nuclear Waste Technical Review Board**


Presented by:
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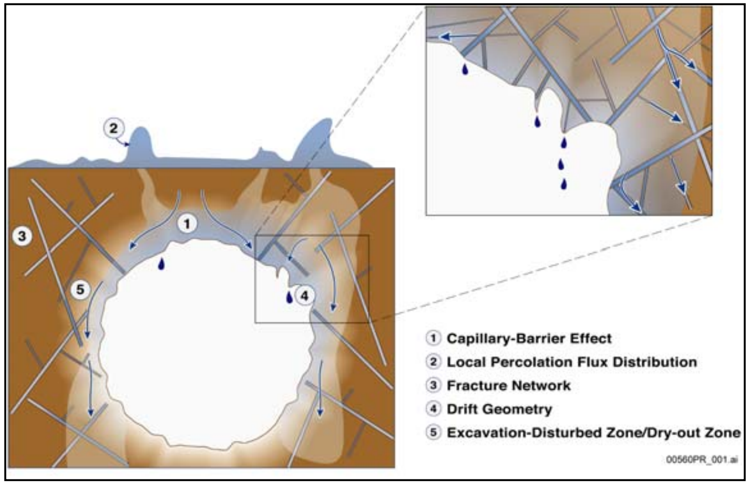
# Mass Flux of Water Out of Drifts Outline

- **Seepage Water Mass Balance**
  - Engineered Barrier System (EBS) Flow Model
  - Flux Diversion Algorithm (drip shield and waste package)
- **In-Drift Condensation Model**
  - Model Development
  - Results and Abstraction
- **Partitioning of EBS Flow to Unsaturated Zone (UZ) Fractures and Matrix**

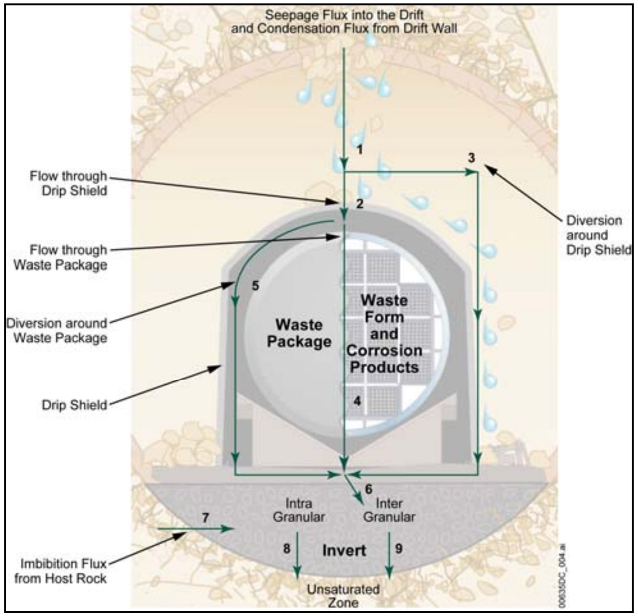
# Mass Flux of Water Out of Drifts

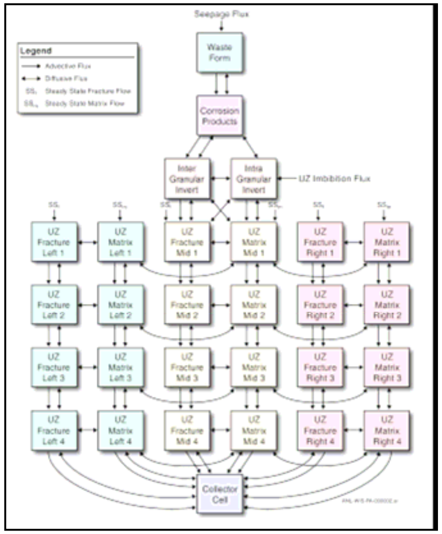
*What key processes affect these estimates?*

– **Seepage, thermal seepage, and drift-wall condensation processes**




– **Flux diversion**

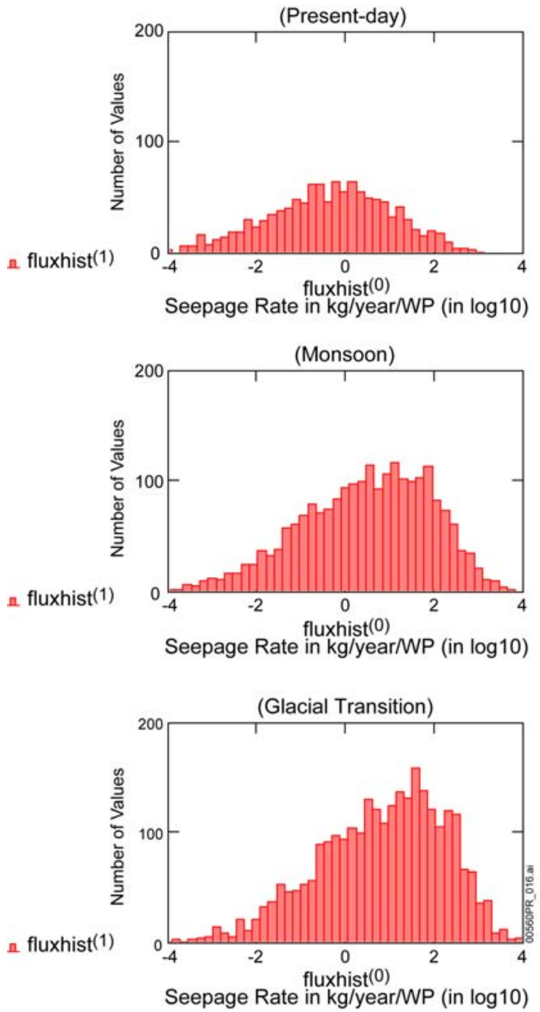



– **Partitioning of EBS outflow to the UZ fractures and matrix**

# Mass Flux of Water Out of Drifts (Continued)

*What is the mass flux of water seeping into and out of drifts over time?*




Source: MDL-NBS-HS-000019 Rev. 01, Figure 6.8-1.

- **EBS flow model continuity: outflow = inflow**
- **Histograms of seepage inflow per waste package (WP) location, where seepage occurs**
- **Seepage occurs at approx. 24% of WP locations***
- **Temporal/spatial variation is controlled by seepage model**
- **Correlated to percolation flux magnitude**

***** (Tptpll, mean percolation, glacial transition)

# Mass Flux of Water Out of Drifts (Continued)

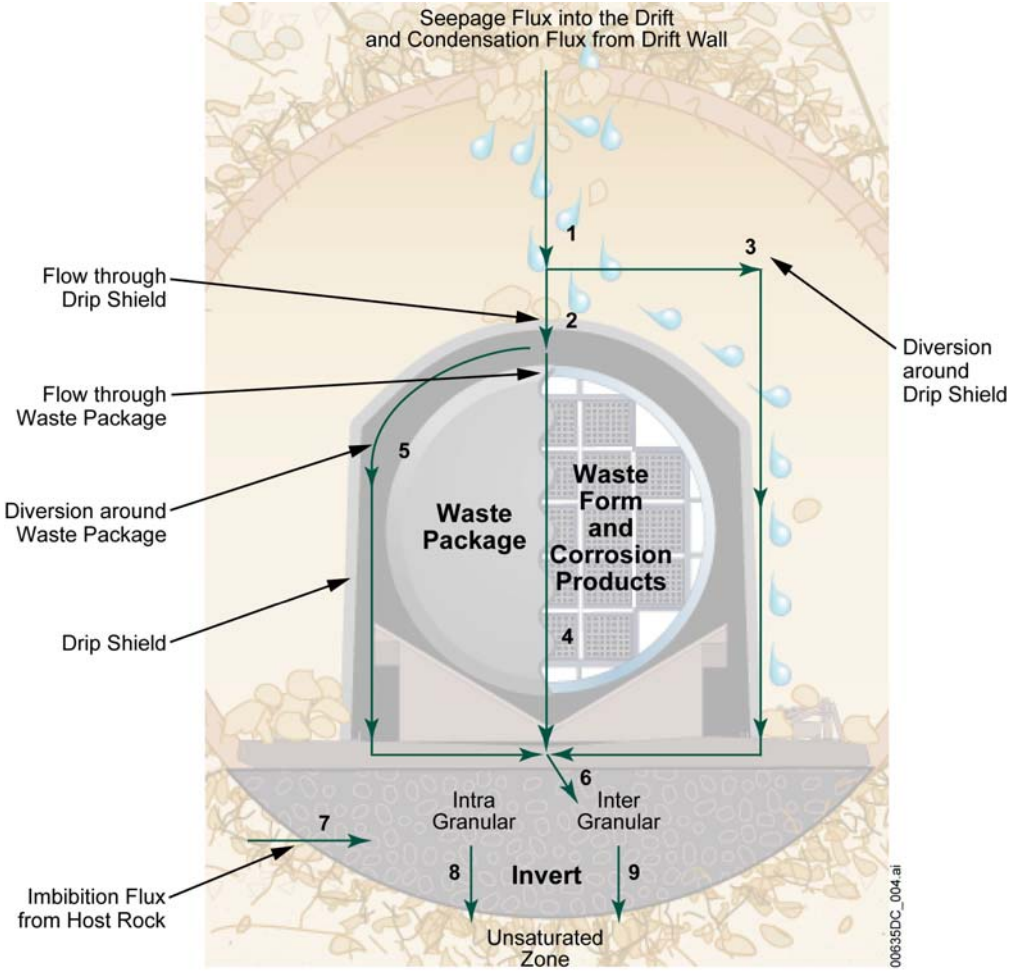
*What is the technical basis for the models used to estimate water mass flux into and out of the drifts over time?*

**Continuity:**

F1 = F2 + F3 = F6

F2 = F4 + F5

F6 + F7 = F8 + F9




Source: ANL-WIS-PA-000001 Rev. 02. (Eq. 6.3.2.4-2)

# Mass Flux of Water Out of Drifts (Continued)

*What is the technical basis for the models used to estimate water mass flux into and out of the drifts over time?*

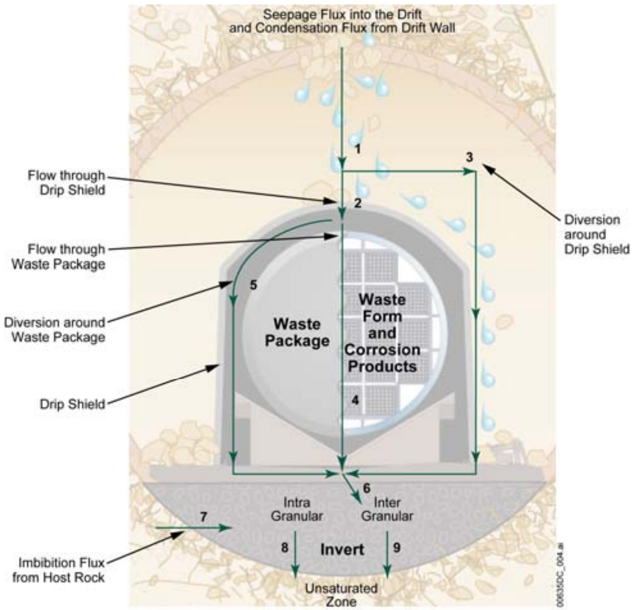
## Flux Splitting Algorithm

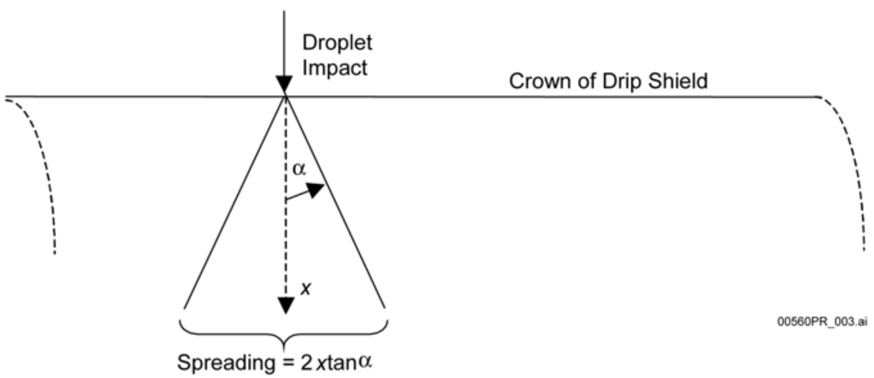
### Drip Shield:

$$F_2 = \min\left[F_1 \frac{N_b l}{L_{DS}} f'_{DS},\ F_1\right]$$

### Waste Package:

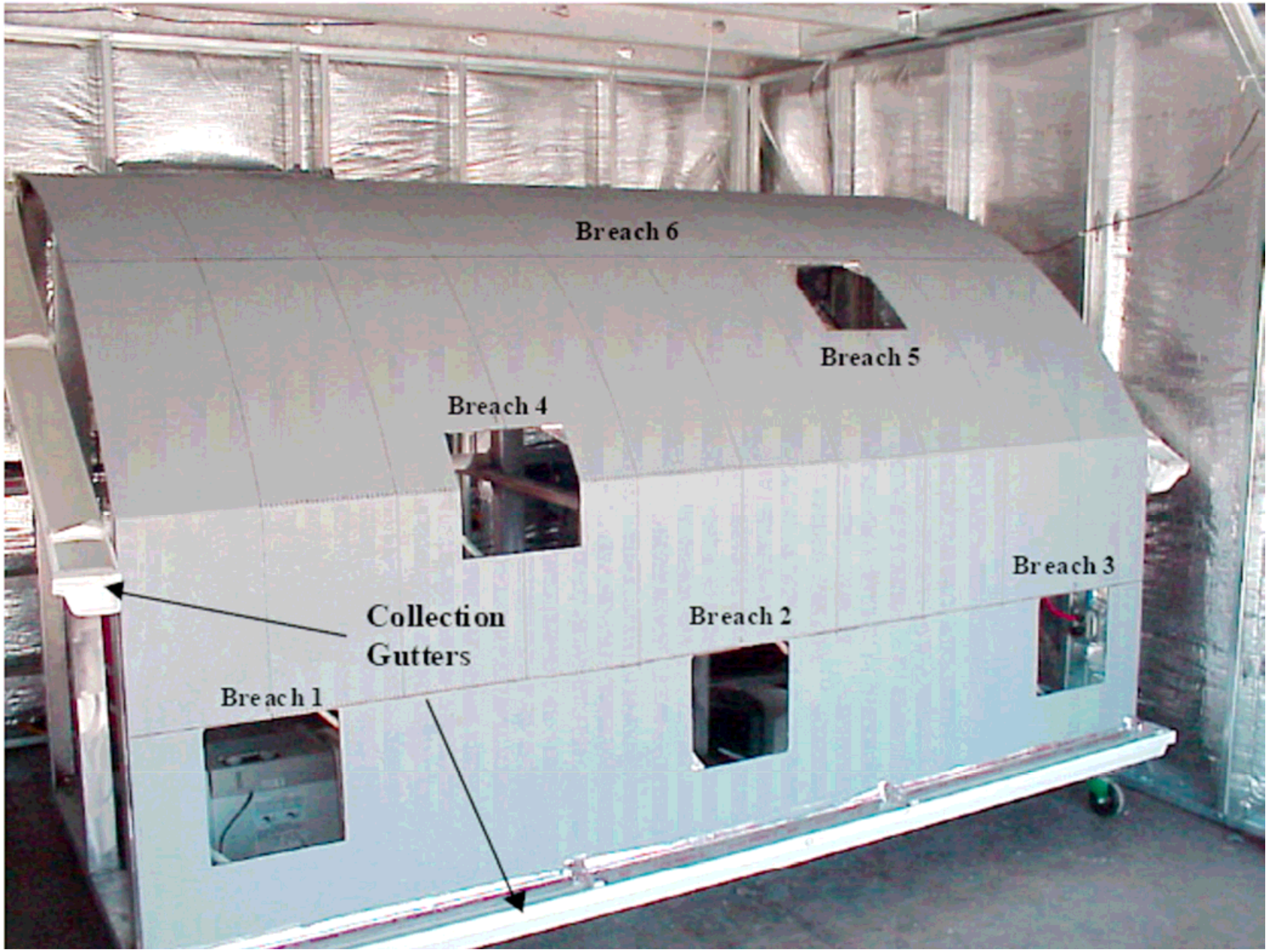
$$F_4 = \min\left[F_2\left(\frac{N_{bWP} l_{WP}}{L_{WP}}\right) f'_{WP},\ F_2\right]$$




Source: ANL-WIS-PA-000001 Rev. 02 (Eq. 6.3.2.4-2 and Eq. 6.3.3.2-3)

# Mass Flux of Water Out of Drifts (Continued)




**Full-scale breached drip shield test setup**

(TDR-EBS-MD-000025 Rev. 00, Figure 5)

# Mass Flux of Water Out of Drifts (Continued)

*What are the assumptions and uncertainties associated with these estimates?*

## Seepage Mass Balance and Flux Diversion

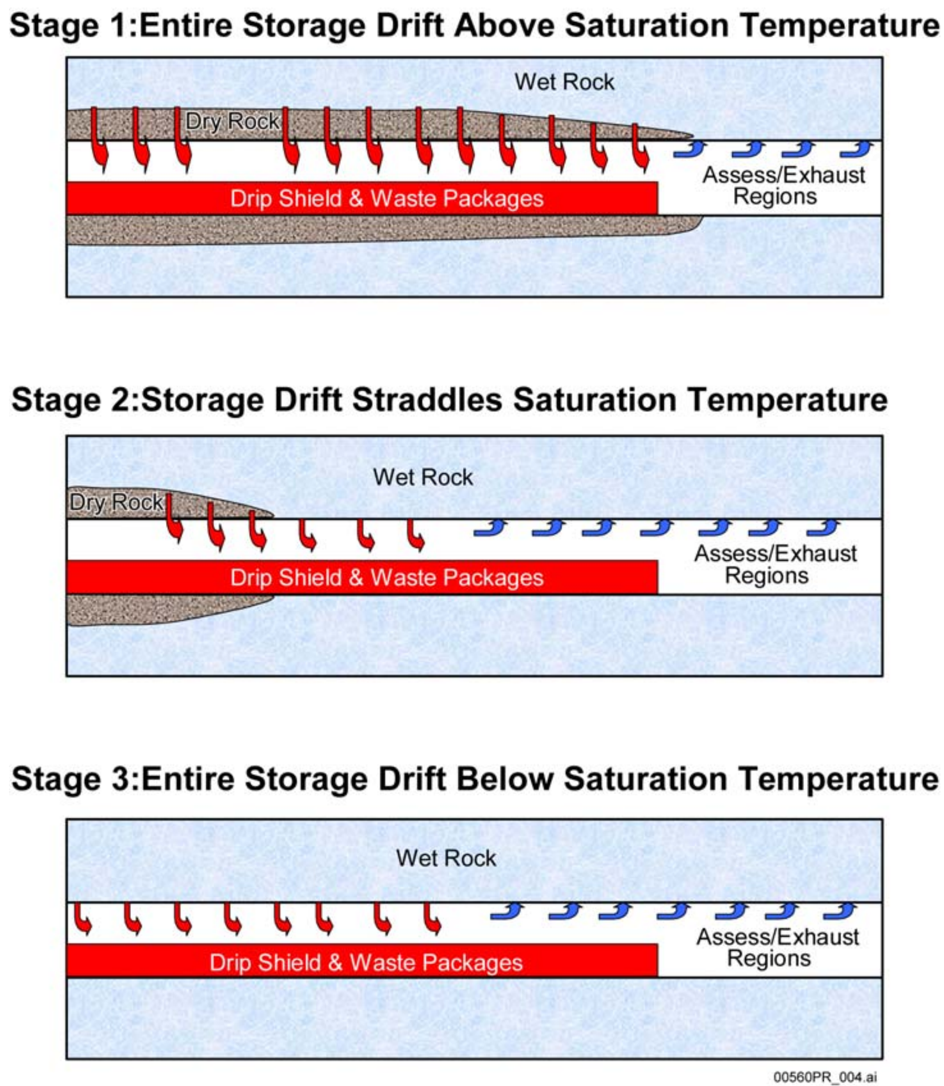
- **Key Assumptions**
  - Seepage impinges directly on top of drip shields (maximizes availability for flow through breaches)
  - All leakage through drip shields impinges on waste packages (maximizes availability)
  - Average diversion response (many drip shields) is unchanged by mineral scale or debris
- **Key Uncertainties**
  - Rivulet runoff angle and splashing effects

# Mass Flux of Water Out of Drifts In-Drift Condensation Model

- **Development motivated by observations underground at Yucca Mountain, and analogs**
- **Evaporation-condensation is limited by availability of moisture, not thermal-power over 10,000 yr**
- **Modeling Objective: Represent drift-wall condensation contribution to advective transport of radionuclides in the EBS**
- **Drift-wall condensation is applied as an additional source of water**
  - **Treated as seepage (F1); can flow through breached drip shields or waste packages**
  - **Included in downstream water mass balance**

# In-Drift Condensation Model (Continued)

- **Stages of evaporation/ condensation**
  1. **Vapor is driven outside emplacement area by boiling at the drift wall**
  2. **Vapor driven by boiling; condensation possible near waste packages**
  3. **Vapor transported by dispersive mixing (condensation model)**

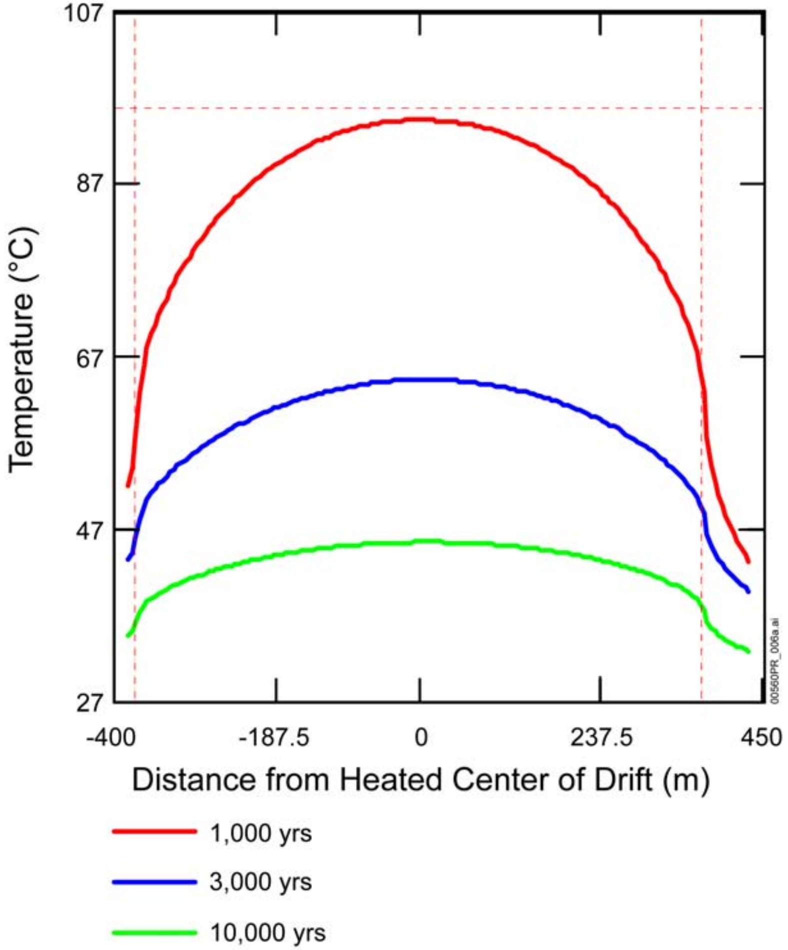


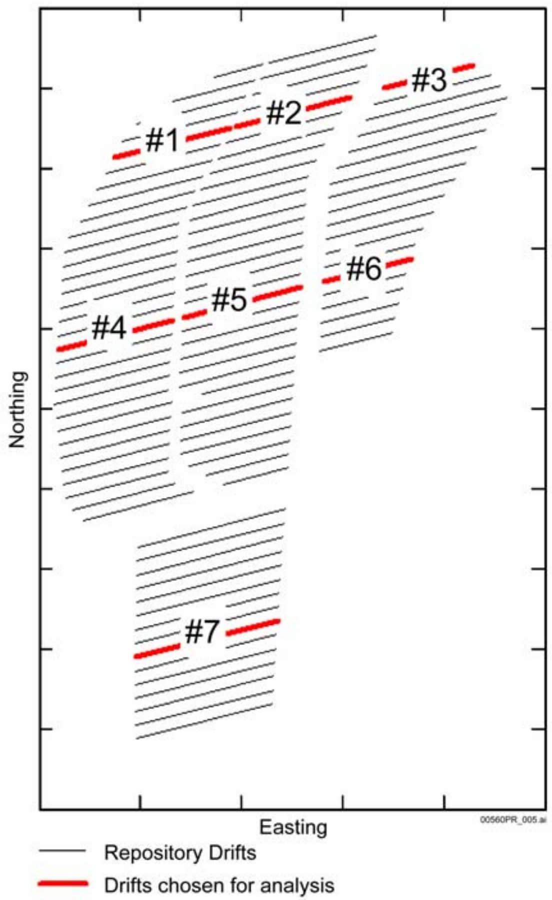

Source: MDL-EBS-MD-000001 Rev. 00, Figure 6.3.3-8.

# In-Drift Condensation Model (Continued)

*What is the technical basis for the models used to estimate water mass flux into and out of the drifts over time?*

**Drift #7 line-load drift-wall temperature super-position calculation**



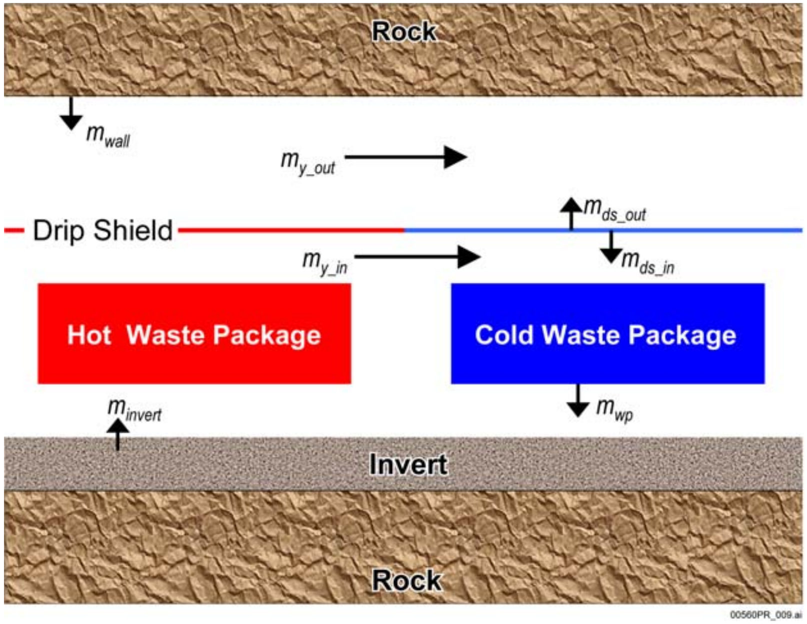




Source: MDL-EBS-MD-000001 Rev. 00, Figure 6.3.5-13.

# In-Drift Condensation Model (Continued)

*What is the technical basis for the models used to estimate water mass flux into and out of the drifts over time?*

- **Network model:**
  - Mass balance
  - Radiative + convective heat transfer
  - Steady-state at 1,000, 3,000, 10,000 yr
  - Nodes at each waste package location
    - Waste package, drip shield (DS)(upper & lower)
    - Invert (top & bottom)
    - Drift wall
    - Air volumes (above/below DS)
  - Unheated end regions included



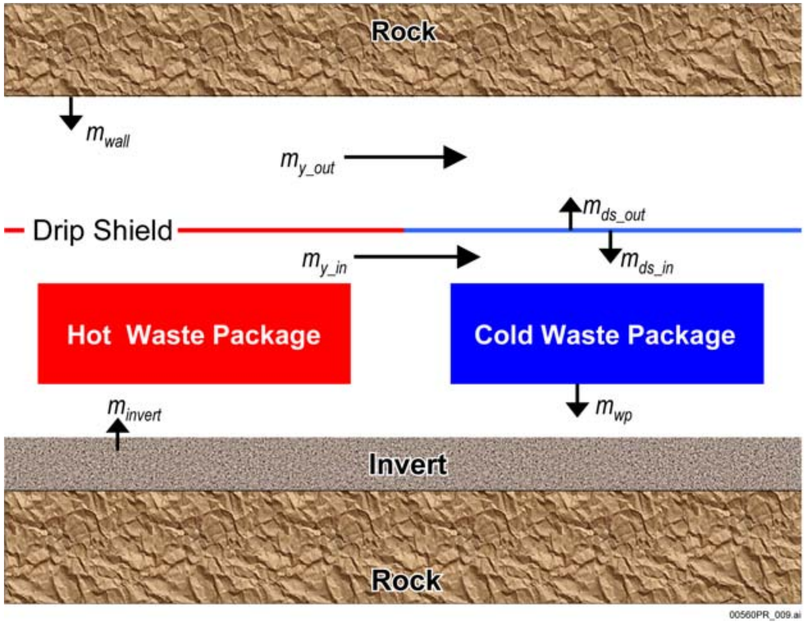

**Schematic of Mass Fluxes**

(Source: MDL-EBS-MD-000001 Rev. 00, Figure 6.3.5-21)

# In-Drift Condensation Model (Continued)

*What is the technical basis for the models used to estimate water mass flux into and out of the drifts over time?*

- **Source conditions:**
  - Evaporation
    - Source vapor pressure = saturation vapor pressure
    - Applied at drift wall or invert nodes
  - Evaporation rate ≤ percolation intercepted by drift footprint
  - Evaporation rate limited by mass transfer correlations




**Schematic of Mass Fluxes**

(Source: MDL-EBS-MD-000001 Rev. 00, Figure 6.3.5-21)

# Mass Flux of Water Out of Drifts
# In-Drift Condensation Model

- **Dispersion Coefficients Represent Axial Transport of Water Vapor by Convective Mixing**
  - 3-D Computational Fluid Dynamics (CFD) simulations
    - Steady-state, single-component (dry air)
    - Waste package arrangement (14 total); drip shields represented explicitly
    - 5 meters of surrounding rock (fixed-temperature outer boundary from repository superposition solution, with and without axial "tilt")
    - Non-buoyant tracer at fixed concentrations; calculated flux
  - Dispersion Coefficient (D) vs. Binary Diffusion Coefficient ($D_0$)
    - Range: $D \approx 200 \times D_0$ to $D \approx 4{,}700 \times D_0$ (uniform vs. "tilted" temperature boundary condition)

# In-Drift Condensation Model (Continued)

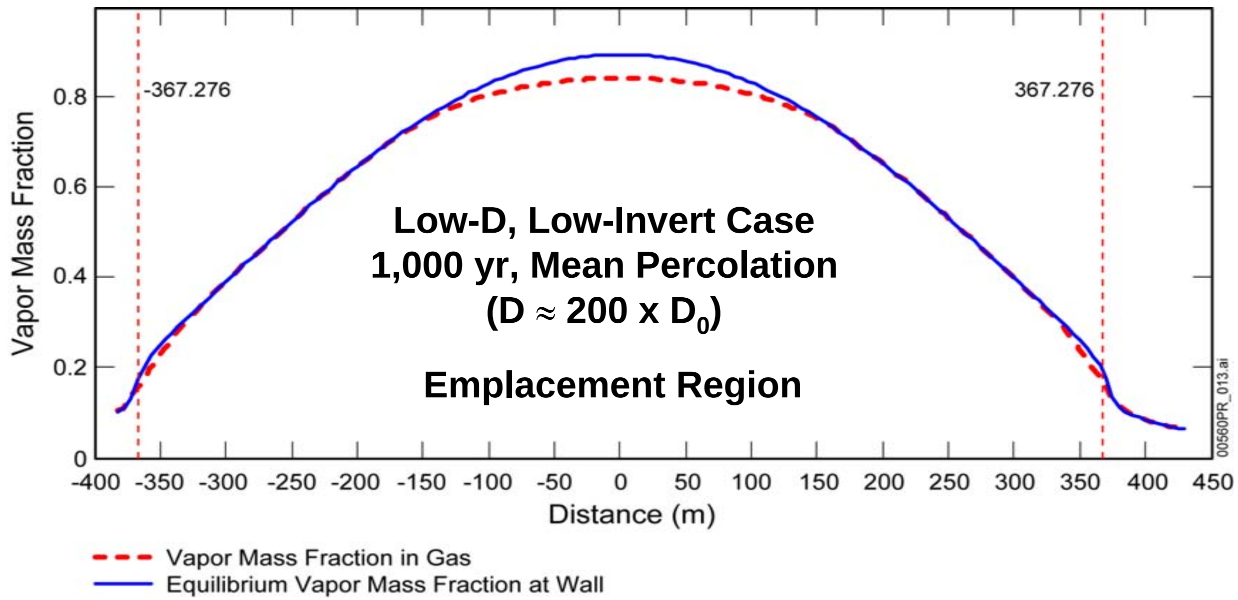
*What are the assumptions and uncertainties associated with these estimates?*

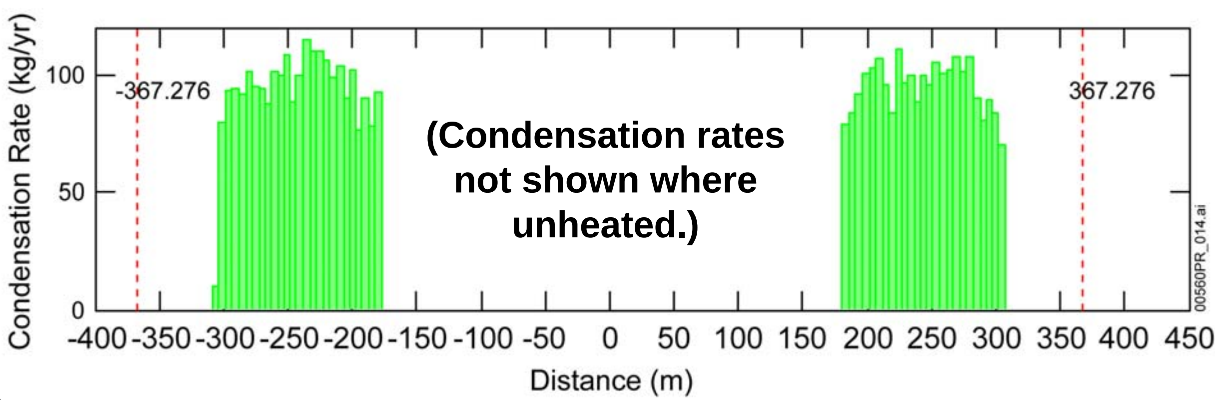
- **Key Assumptions**
  - Source condition for evaporation (saturated vapor pressure at drift-wall or invert maximizes availability)
  - Invert transmissive to vapor, but not heat (maximizes evaporation for high-invert cases)
  - Axial heat transport (as latent heat) is insignificant
- **Key Uncertainties**
  - Liquid saturation distribution in the invert (low/high invert)
  - Ventilation of air volume under drip shield (vs. non-ventilated)
  - Dispersion coefficient (low/high D)
    - Increased axial mass transport (barometric pumping, large-scale circulation) increases condensation in unheated regions

# In-Drift Condensation Model (Continued)

*How does the mass of water seeping into and out of the drifts vary temporally and spatially?*

- **Drift #7 Example Results**
  - “Ventilated” drip shield
  - Condensation rate (kg/yr/WP)
  - Condensation occurs if vapor mass fraction > equilibrium vapor mass fraction
  - Magnitude comparable to seepage (0 to >$10^2$ kg/yr/WP)



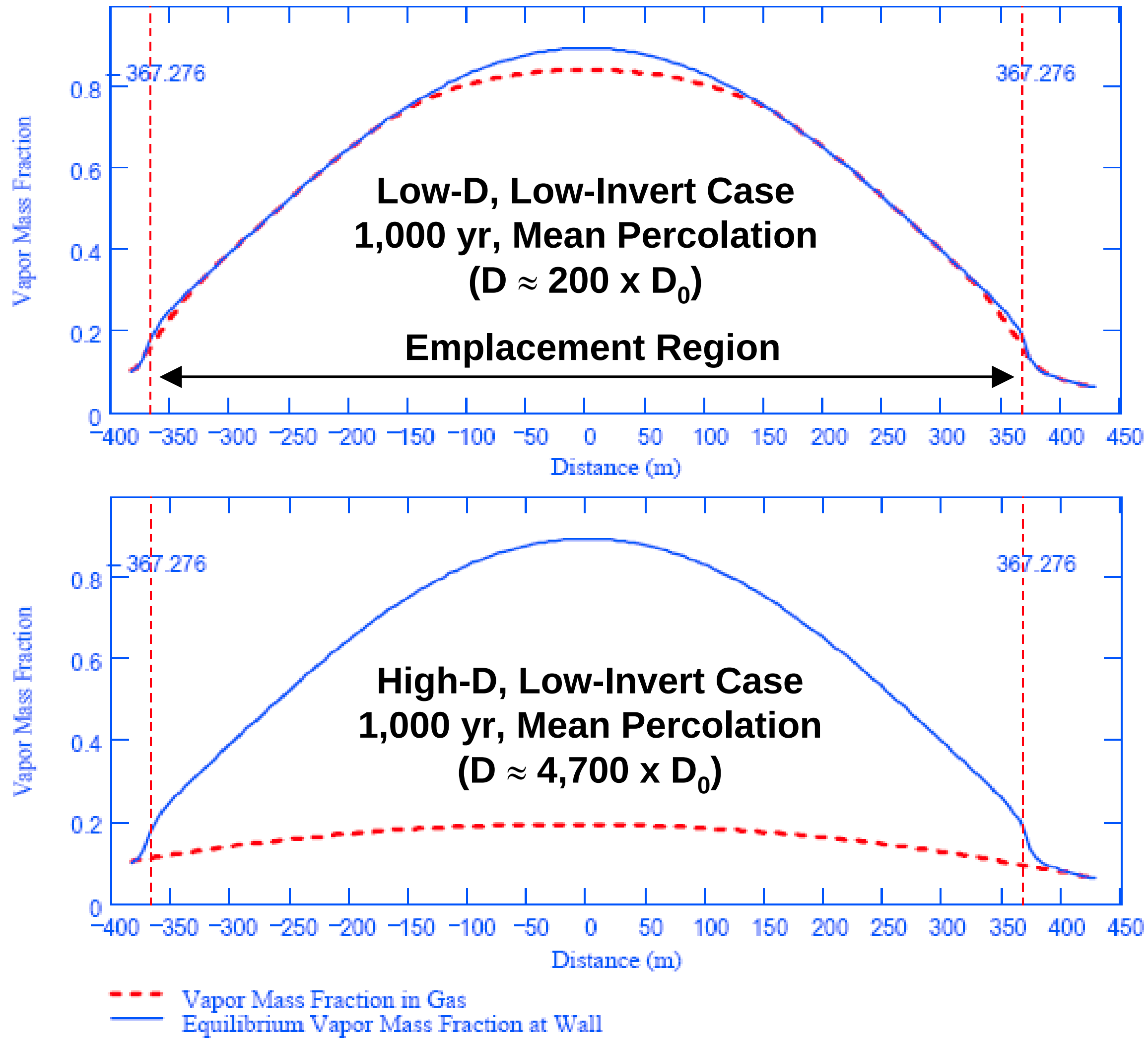




Source: MDL-EBS-MD-000001 Rev. 00, Figure 6.3.7-2.

# In-Drift Condensation Model (Continued)

*How does the mass of water seeping into and out of the drifts vary temporally and spatially?*

- **Drift #7 Example Results, (Continued)**
  - **Compare low-D vs. high-D**
  - **Condensation if vapor mass fraction equilibrium vapor mass fraction**




Source: MDL-EBS-MD-000001 Rev. 00, Figures 6.3.7-2 and 6.3.7-4.

# In-Drift Condensation Model (Continued)

*What are the assumptions and uncertainties associated with these estimates?*

## Propagation of Model Uncertainty

- **Key uncertainties are represented with bounding conditions or parameter ranges**
  - Evaporation at bottom vs. top of invert (low-invert and high-invert conditions)
  - Ventilated vs. non-ventilated air volume under drip shields
  - Low-D and high-D axial drift-air dispersion coefficients

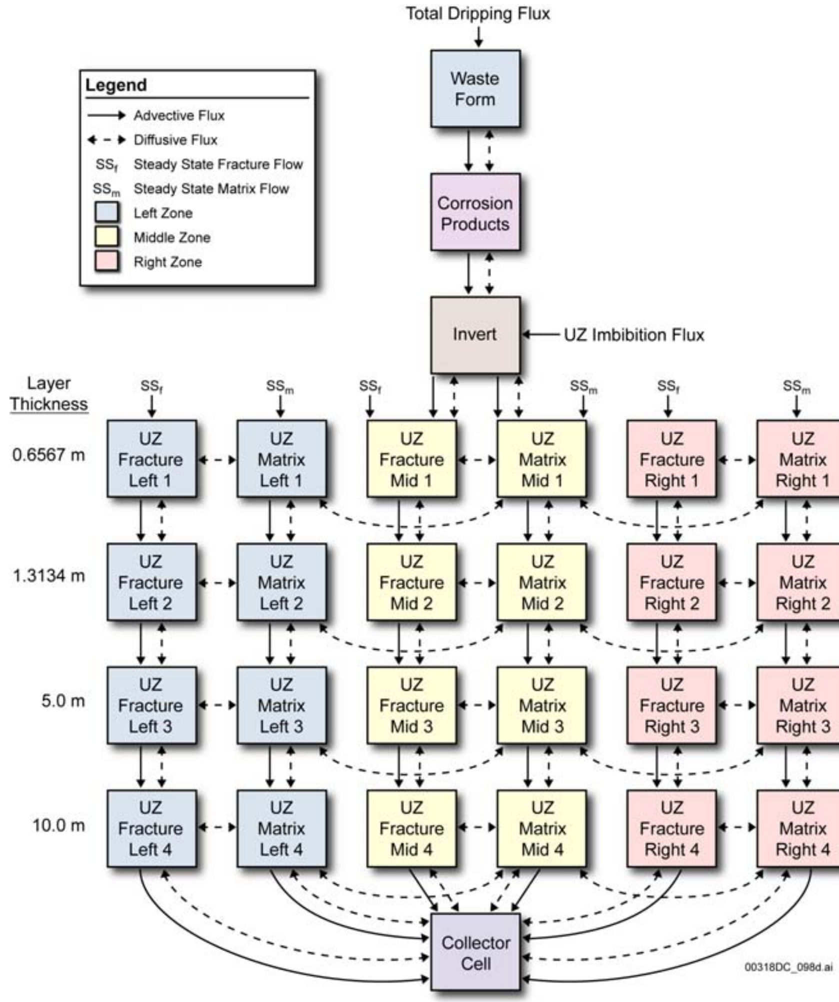
| | "Ventilated" Drip Shield | | "Non-Ventilated" Drip Shield | |
|---|---|---|---|---|
| | Low Dispersion | High Dispersion | Low Dispersion | High Dispersion |
| High-Invert | Case 1 | Case 2 | Case 5 | Case 6 |
| Low-Invert | Case 3 | Case 4 | Case 7 | Case 8 |

# In-Drift Condensation Model (Continued)

- **Abstraction for Use in System-Level Modeling:**
  - Use results for “ventilated” drip shield (representing mass transfer through joints and invert ballast)
    - Consistent with multiscale model; 4 equally weighted cases
  - Use drift-wall condensation
    - Condensation on drip shields or waste packages is evaluated in feature, event, and process (FEP) exclusion justifications
  - Develop statistical correlations
    - Correlation for the fraction of waste package locations where drift-wall condensation occurs, vs. percolation flux
    - Correlation for the magnitude of drift-wall condensation, vs. percolation flux
    - Combining results for all percolation flux conditions

# Mass Flux of Water Out of Drifts
# EBS-UZ Interface Fluxes

- **Fracture-matrix flow partitioning**
  - **Mass flux from the invert (F8 + F9) flows into the Unsaturated Zone (UZ)**
  - **(Seepage + drift-wall condensation) flows into the UZ fractures**
  - **Imbibition flux into the invert (F7) flows into the UZ matrix**
- **Approach addresses the “drift-shadow” effect**




Source: ANL-WIS-PA-000001 Rev. 02, Figure 6.5-4.

# Mass Flux of Water Out of Drifts Summary

- **EBS Flow Model**
  - Seepage water mass balance + drift-wall condensation
  - Flux diversion based on experiments
- **Condensation Model**
  - Response to field observations and analogs
  - Modeling objective: to address effects on advective transport of radionuclides in the EBS
  - Mass balance model, with parameter ranges for key uncertainties
  - Model results summarized in statistical correlations (vs. percolation flux)

# Mass Flux of Water Out of Drifts Summary (Continued)

- **EBS-UZ Flow Partitioning**
  - Sensitivity studies show that much of the drift-shadow effect is a function of fracture-matrix partitioning
  - Seepage + drift-wall condensation = advective flow in UZ fractures below the invert
  - Seepage + drift-wall condensation cause radionuclide partitioning to UZ fractures

# Backup

# In-Drift Condensation Model (Backup)

*What is the mass flux of water seeping into and out of drifts over time?*

- **Results Summary**
  - **Condensation on the drip shield or waste package occurs only with high-invert source condition**
  - **Combines all percolation conditions (lower, mean, upper)**

| | **"Ventilated" Drip Shield** | | **"Non-Ventilated" Drip Shield** | |
|---|---|---|---|---|
| | **Low Dispersion** | **High Dispersion** | **Low Dispersion** | **High Dispersion** |
| **High-Invert** | **DW** – 1,000 yr, 3,000 yr, & 10,000 yr<br>**DS** – None<br>**WP** – None | **DW** – 3,000 yr & 10,000 yr<br>**DS** – None<br>**WP** – None | **DW** – 1,000 yr only<br>**DS** – 1,000 yr, 3,000 yr, & 10,000 yr<br>**WP** – 10,000 yr only | **DW** – None<br>**DS** – 1,000 yr, 3,000 yr, & 10,000 yr<br>**WP** – 10,000 yr only |
| **Low-Invert** | **DW** – 1,000 yr only<br>**DS** – None<br>**WP** – None | **DW** – None<br>**DS** – None<br>**WP** – None | **DW** – 1,000 yr only<br>**DS** – None<br>**WP** – None | **DW** – None<br>**DS** – None<br>**WP** – None |
| **DW** = Drift wall, **DS** = Underside of drip shield, **WP** = Waste package surface | | | | |