U.S. DEPARTMENT OF ENERGY
OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

NUCLEAR WASTE TECHNICAL REVIEW BOARD
FULL BOARD MEETING

SUBJECT: COMBINING PROCESSES: AN ENGINEERED BARRIER SYSTEM SOURCE TERM

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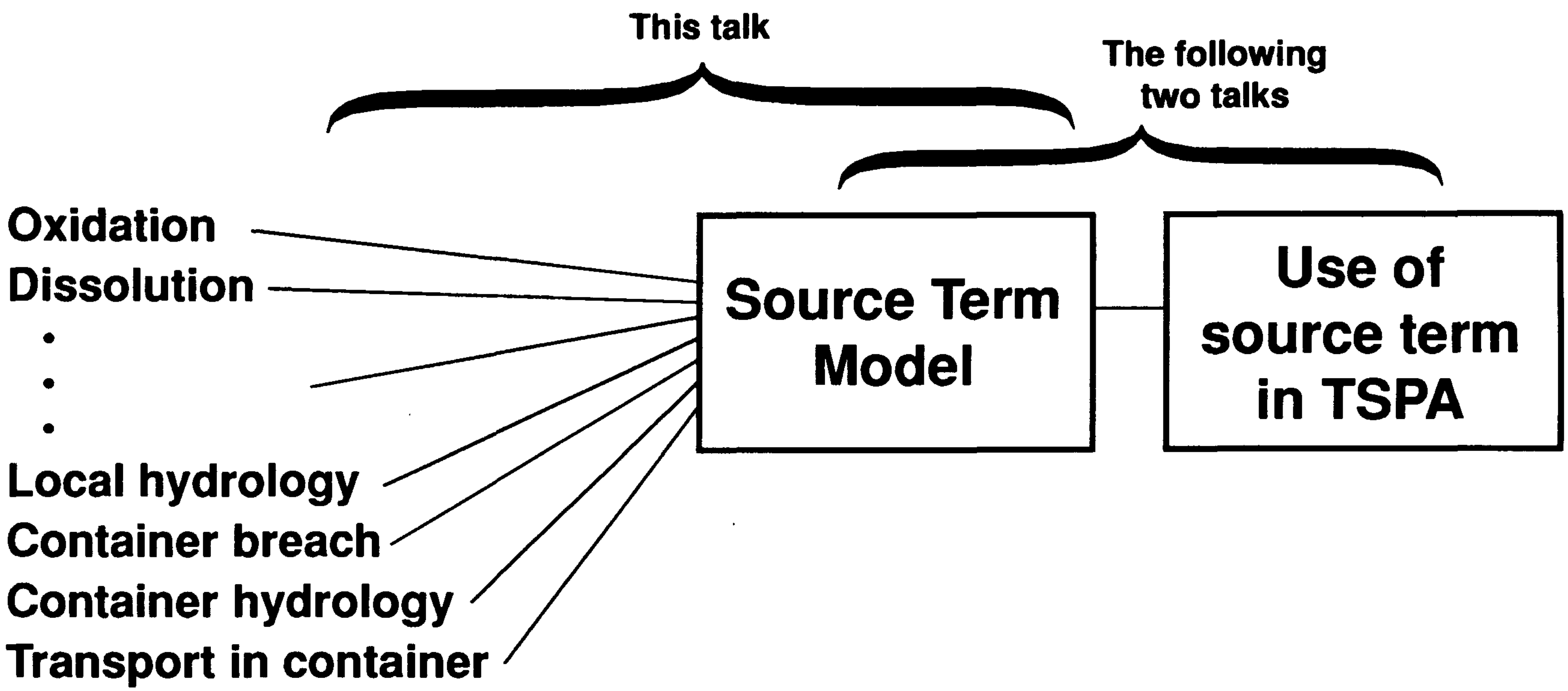
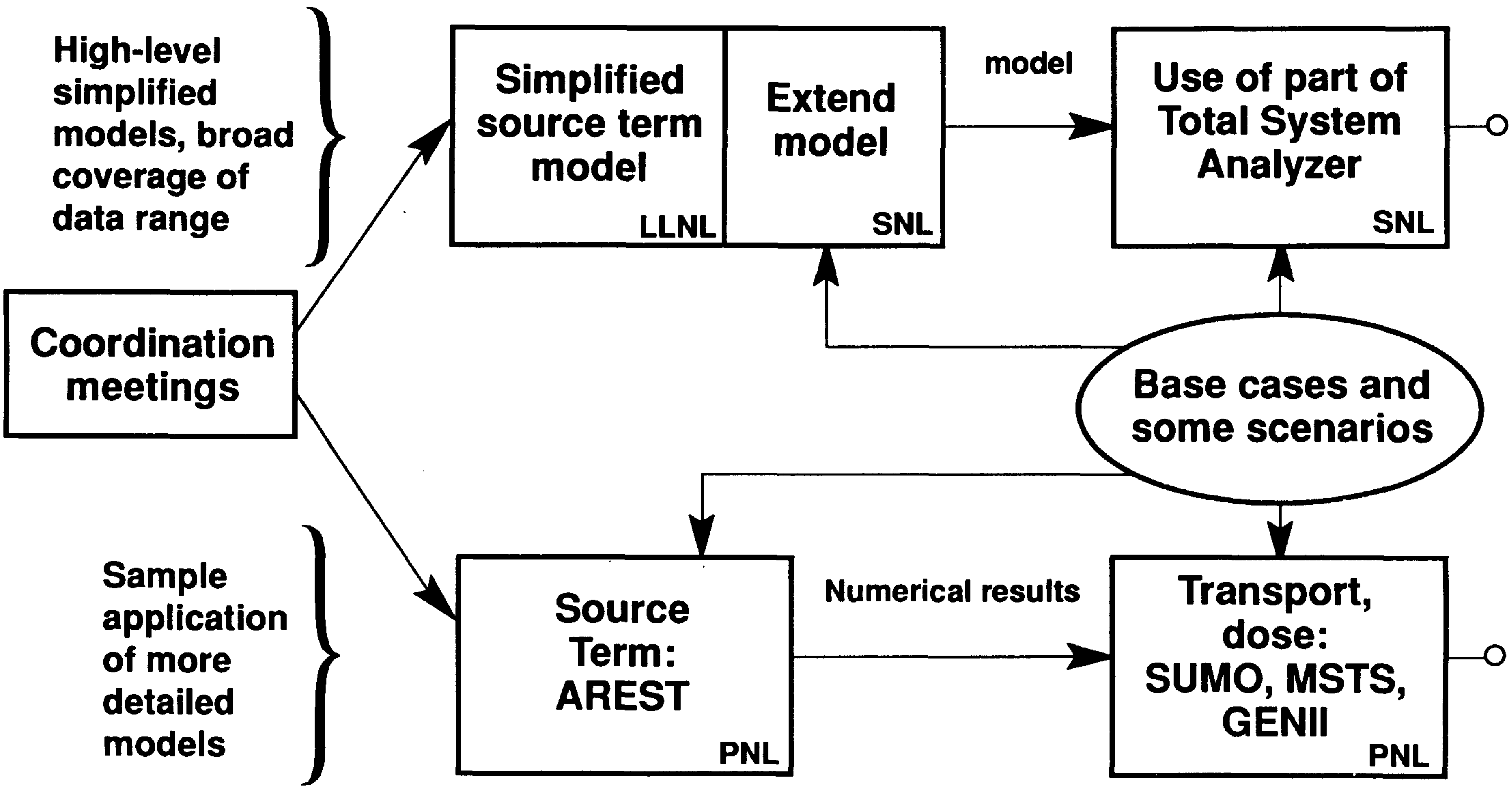
This Morning's Talks by DOE Contractors Focus on the Use of the Detailed Models and Data in Systems-Level Applications

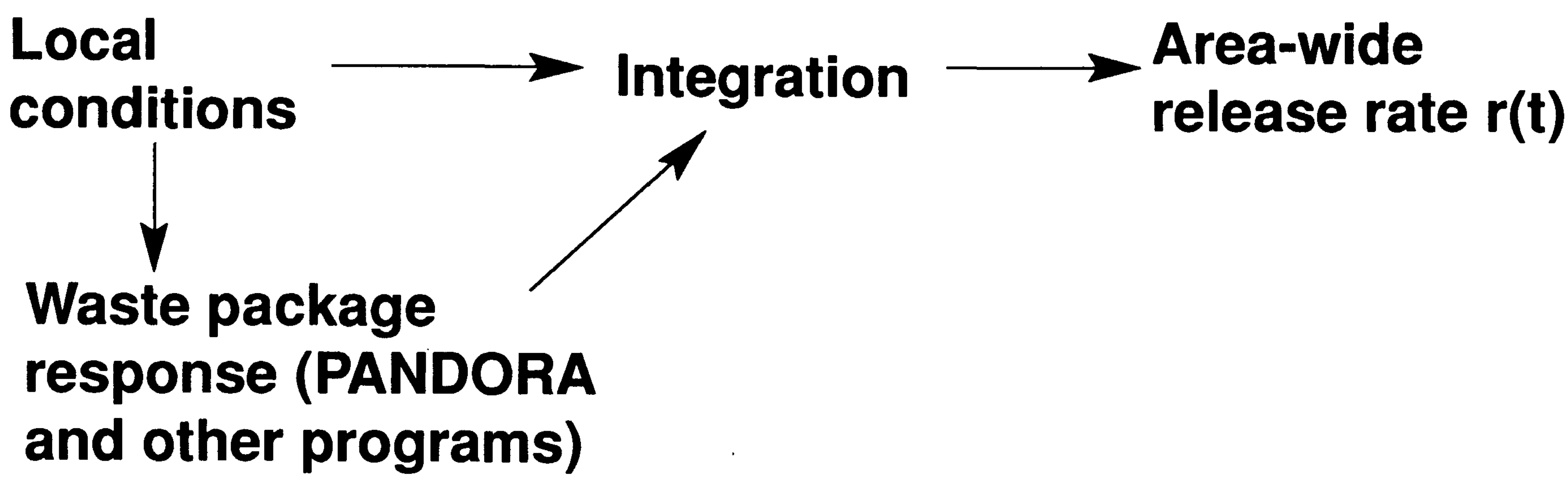


Two Trains of Analyses were Carried out in DOE's TSPA-91 for Complementary Purposes



- Today's talks by LLNL, PNL, and SNL focus on the source term

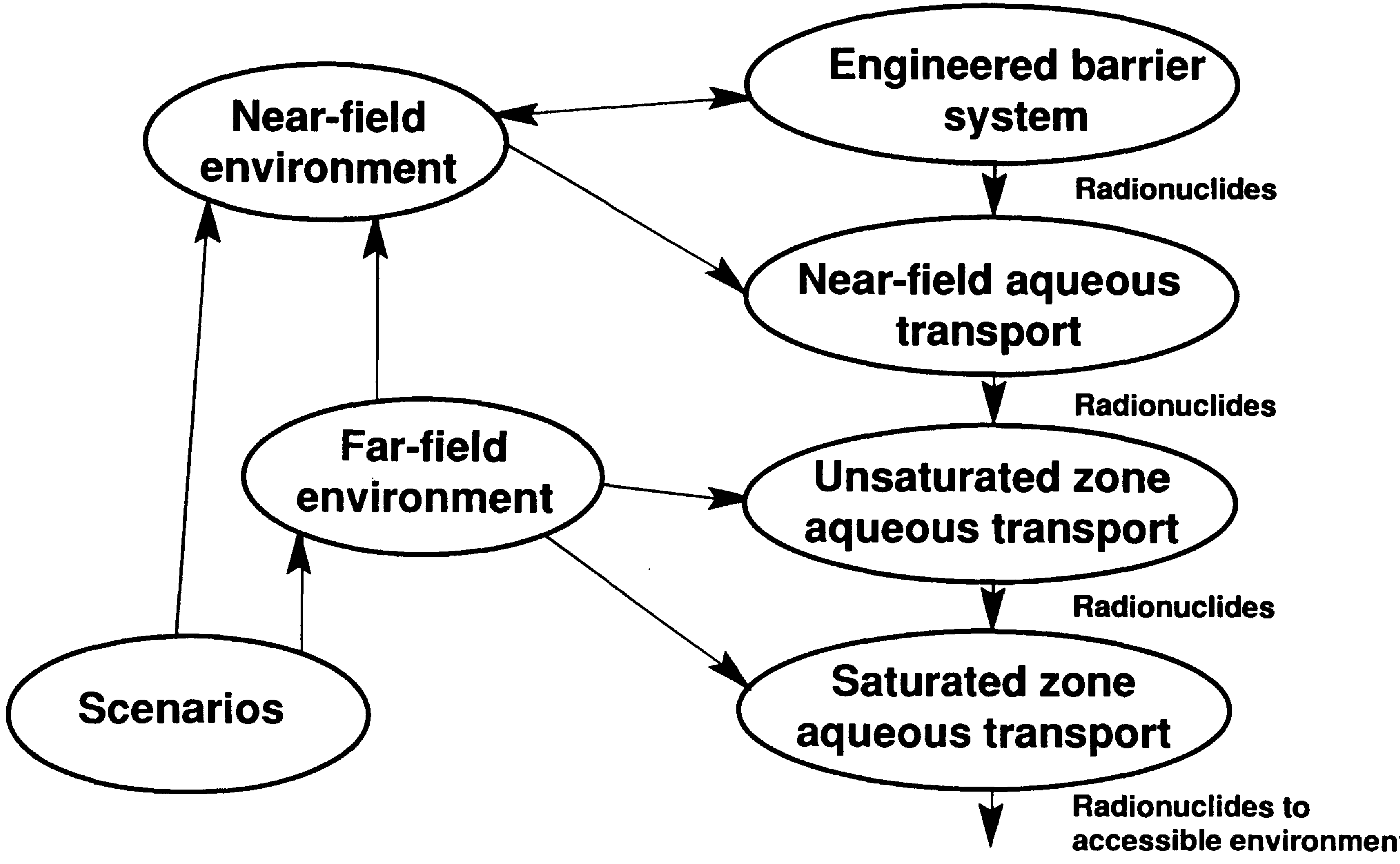
A Source Term Requires Single-Package Behavior and Integration over Packages



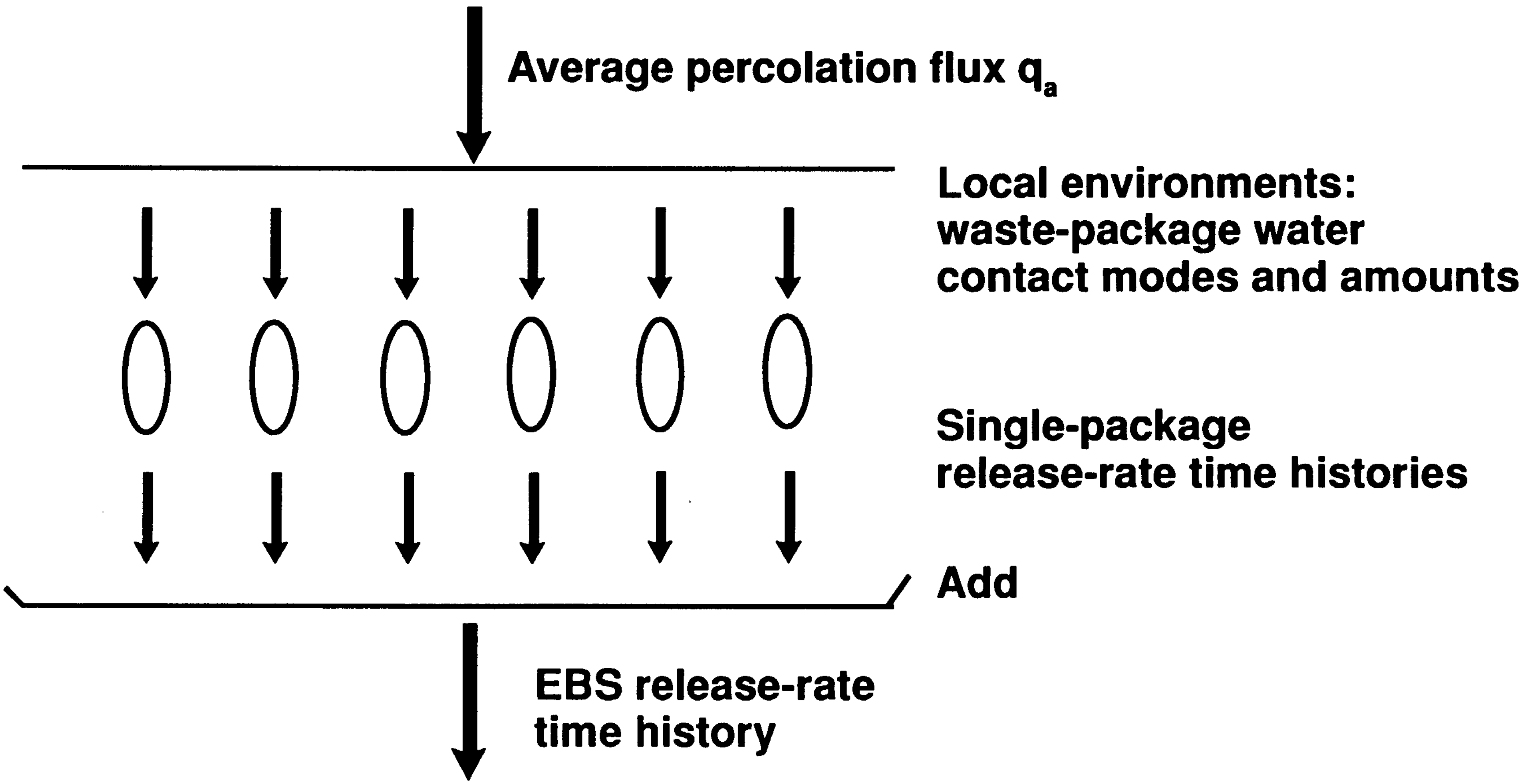
Desired Features of a SourceTerm for Total System Performance Assessment (TSPA)

- Simple
- Has the major features of the process results
- Applicable over a wide range of parameter values
- Uses the total system parameters, where appropriate (q_a, q_o)
  - Percolation flux (q_a)
  - Saturated hydraulic conductivity of porous rock matrix (q_o)

Subsystems Act as Boundary Conditions and/ or Barriers in the Base-Case Aqueous Release



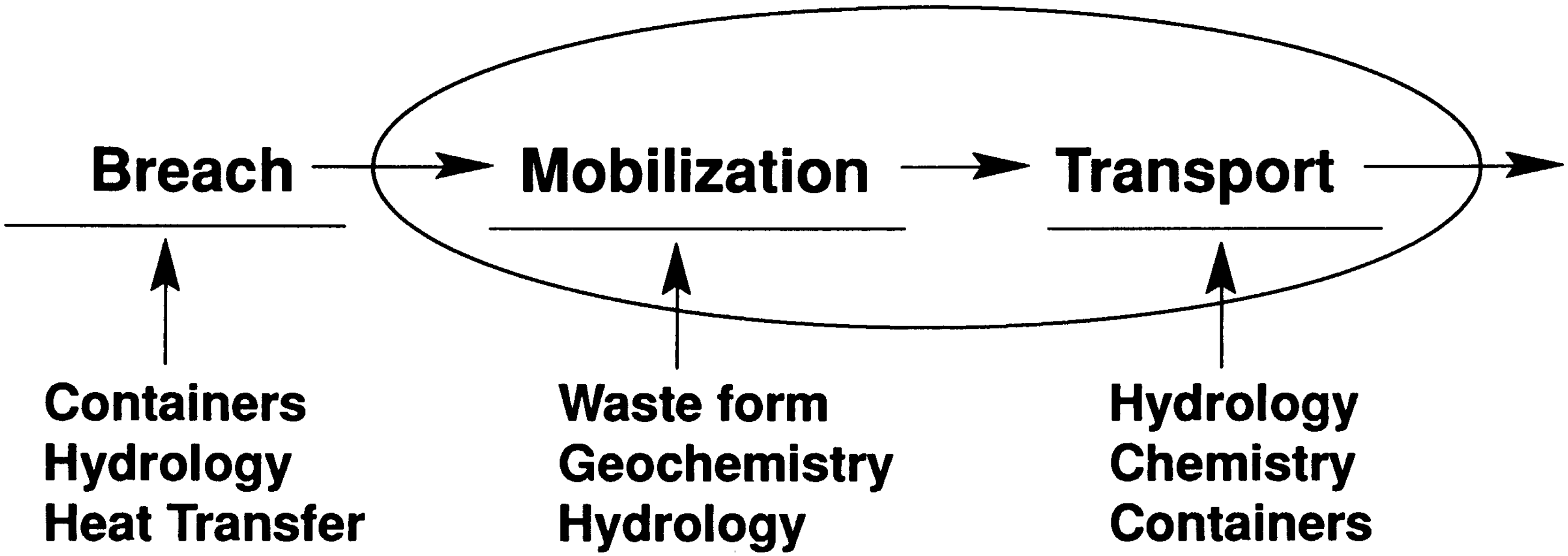
At the Core of the Engineered Barrier System (EBS) are Single Waste Packages with Different Local Environments



Some Issues in the Source-Term Modeling Process

- Linking of processes
  - On single waste packages
  - On area-wide set of waste packages
- Areal averages/localized variations
- Correlations
  - Among inputs
  - Of outputs with inputs

For Single Waste-Package Response, the PACE-90 Working Group 2 Focused on the Processes Near the End of the Causal Chain



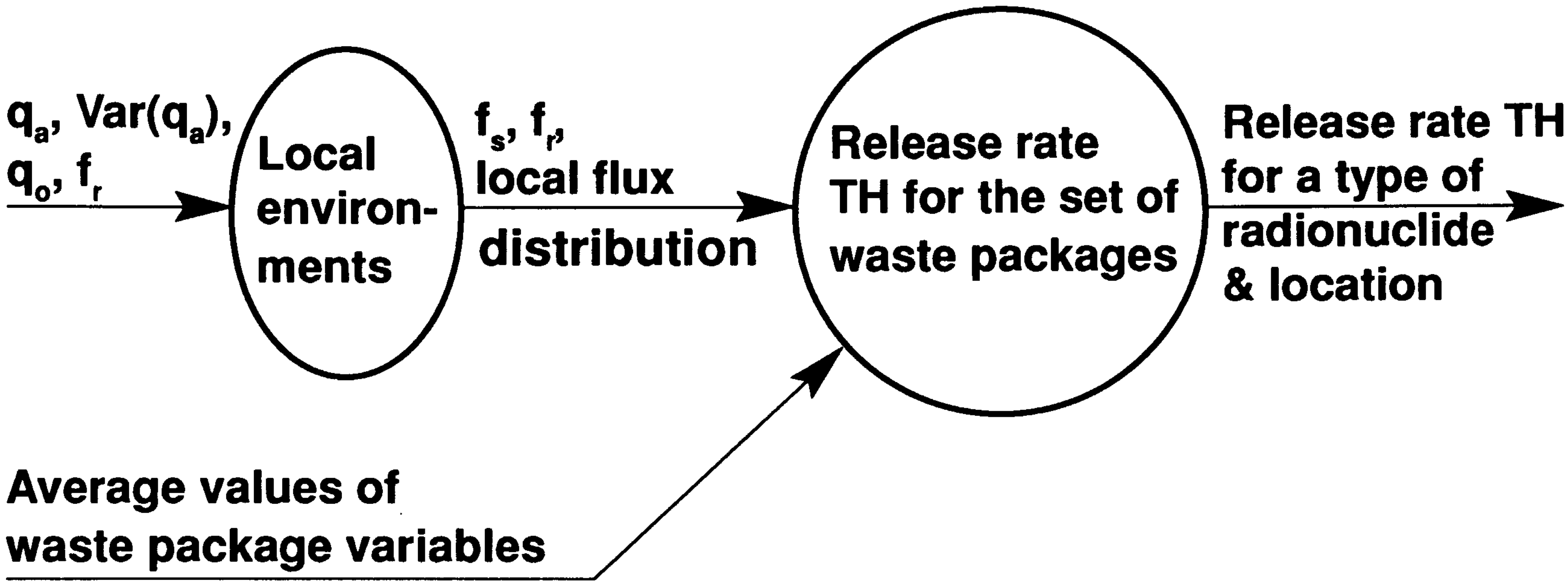
Earlier processes are treated by input data structures

Within a Single Waste Package or a Set, Multiple Alternatives Must be Modeled

EBS transport processes		Radionuclide chemical types		Source location properties
Diffusion Flow-through Bathtub Gaseous only	x	High solubility Low solubility Gas	x	Rapidly accessible location (cladding surface, cladding gap) Matrix location

For each important alternative, an area-integrated result was calculated

First the Distribution Was Determined of Local Environments for the Release Rate Processes



TH: Time history
q_a: Average percolation flux
Var(q_a): Spatial variance of q_a
q_o: Saturated hydraulic conductivity of the porous rock
f_s: Fraction of boreholes with seepage flow
f_r: Fraction of boreholes with rubble

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Areal Averages ⟶ Localized Variations

- The simplified source term for TSPA-91 treated local-environment variability in
  - Hydrology
  - Rock mechanics (for a diffusion pathway)
  - Container breach times

- Within a waste package, a fraction of the spent fuel is wet at any time. The simplified model assumed this fraction is a constant

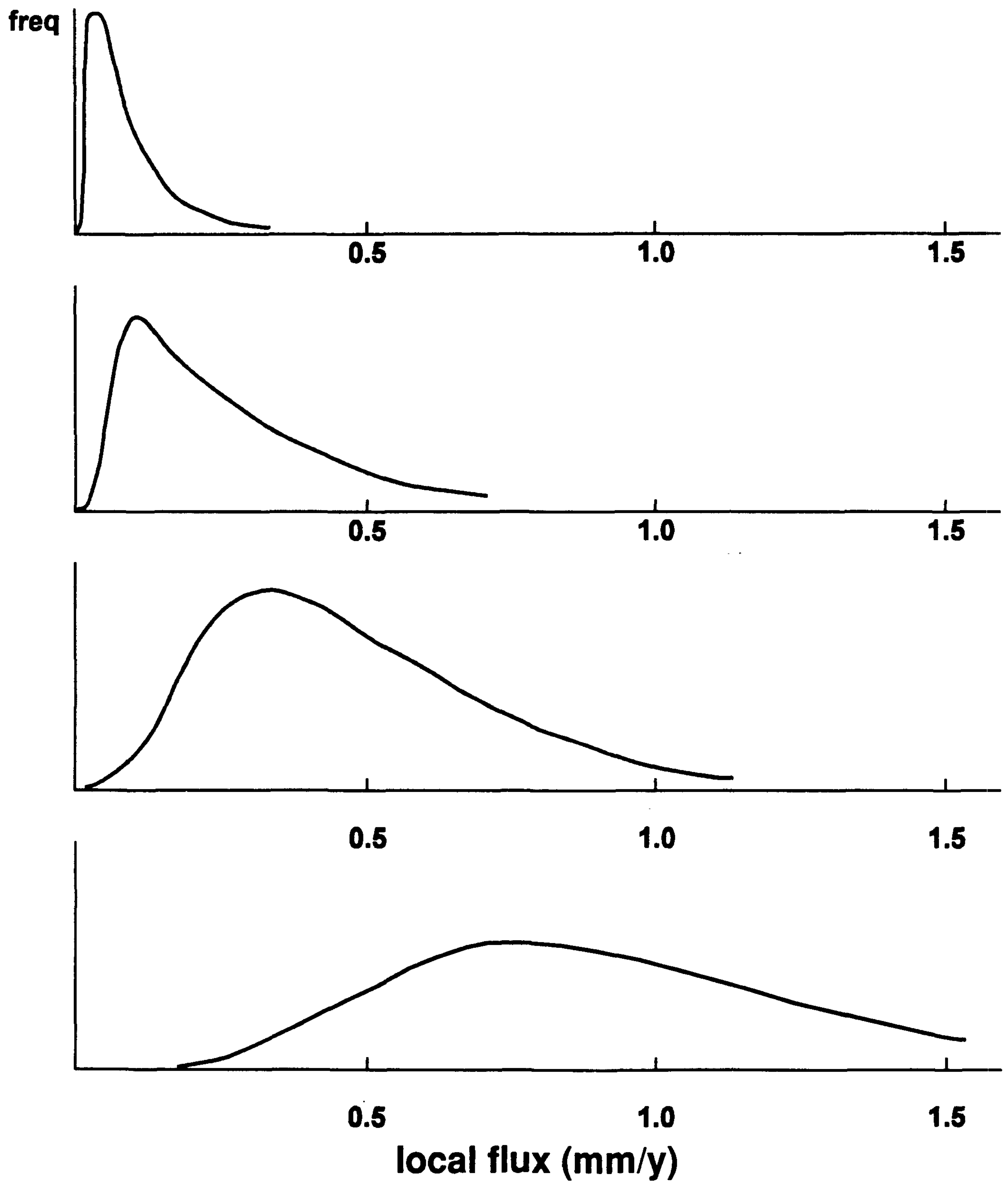
Some Specific Features of the Mountain-Wide Base Case Hydrology for TSPA-91

- The probability distribution of average percolation flux covers a wide range (0 mm/y - 7 mm/y and up)
- As average flux increases, the local environments are expected to change:
  - More waste packages get wet
  - The advective flux at wet packages increases
- The average percolation flux influences both the source term and the far-field transport
- Does the source term change smoothly or as a step function versus the average percolation flux?

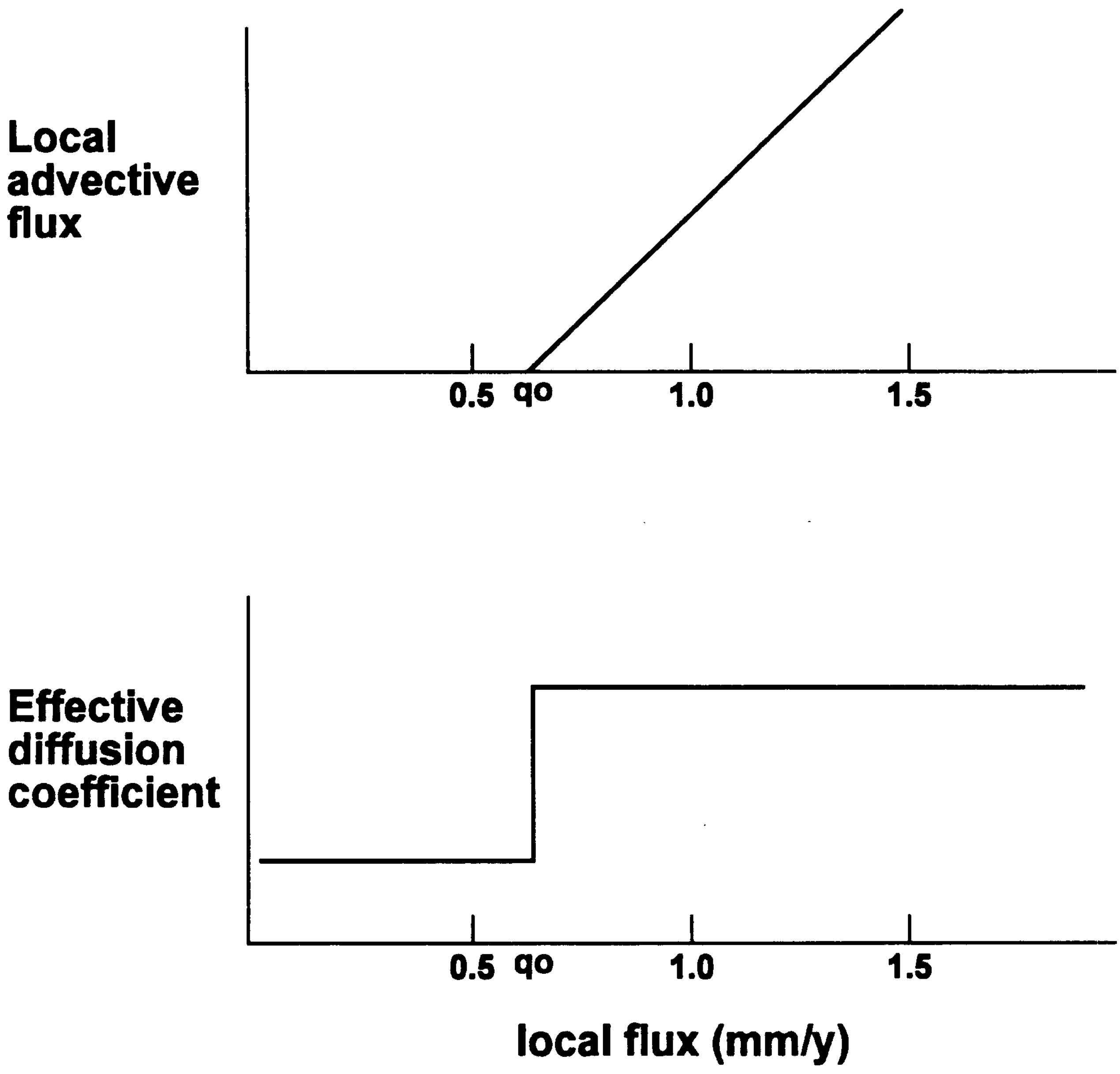
Some Features of the Local-Environments Model

- For a waste package to have water contact, it requires rubble in the borehole, or seeping water, or both
- Local percolation flux is lognormally distributed, with repository-wide average equal to the average percolation flux
- Local seepage or fracture flow occurs if the local water flux exceeds the saturated hydraulic conductivity of the matrix
- Rubble and seepage occurrence are independent
- The effective diffusion coefficient in the rubble depends on whether seepage is present

As the Average Percolation Flux Increases, a Greater Fraction of the Waste Packages Experience the Larger Local Percolation Flux Values



As the Local Percolation Flux Goes Up, the Local Advective Flux and the Effective Diffusion Coefficient Change



Output of the Model: A Distribution of Local Environments

f_r: Fraction of waste-package boreholes with rubble

f_s: Fraction of waste-package boreholes with seepage

Fraction of <u>waste package</u>	Type of <u>water contact mode</u>
$f_s \cdot (1 - f_r)$	Advective, with a distribution of local water flux
$(1 - f_s) \cdot f_r$	Diffusive with low diffusion coefficient
$f_s \cdot f_r$	Combined advective and diffusive with higher diffusion coefficient
$(1 - f_s) \cdot (1 - f_r)$	None

Geochemistry Variation is a Fertile Field for Future Modeling

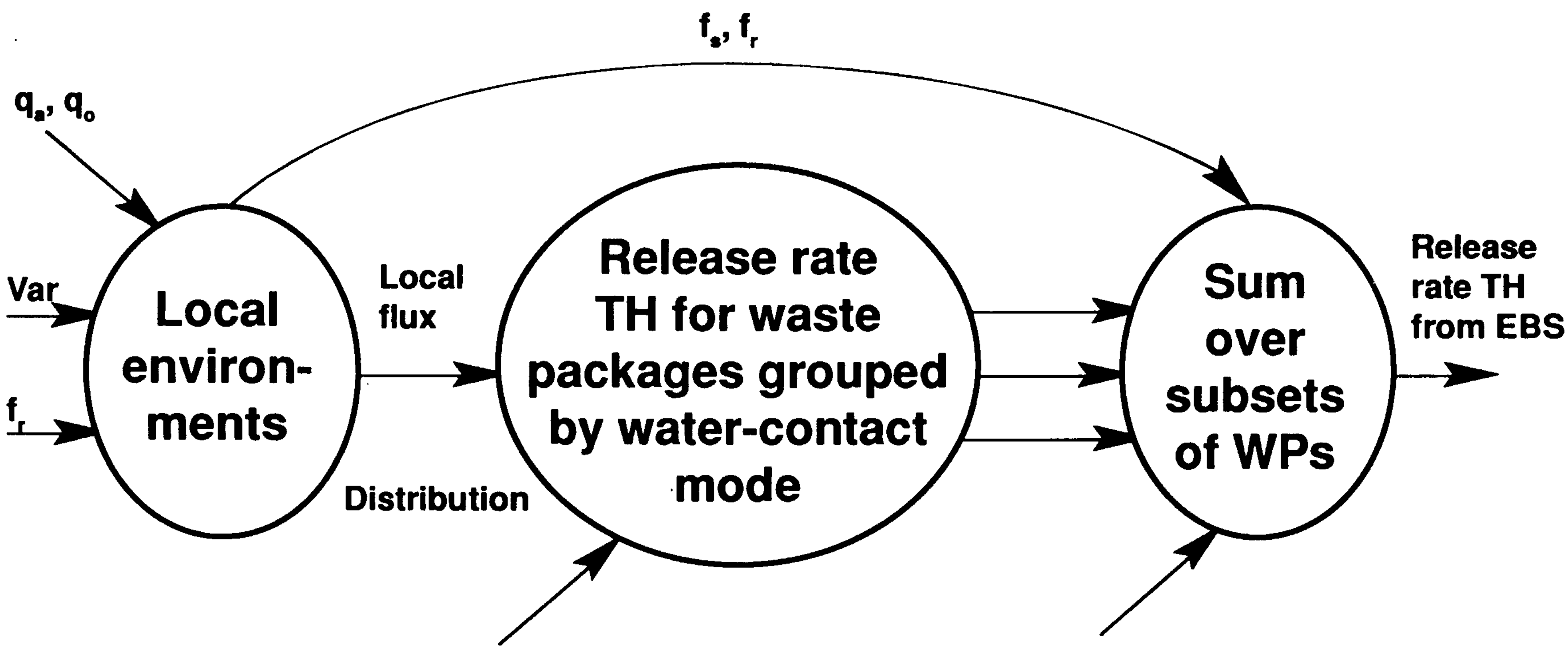
- **Local variability in geochemistry was not treated**
- **Within a waste package, the chemistry will be dependent on the hydrology, specifically on the following:**

$$\frac{\text{Moles Ca /y}}{\text{Moles U reacted /y}} = \frac{\text{Water influx/y x Conc. of Ca}}{\text{Bulk Surface wet} \times \dfrac{\text{Grain surface}}{\text{Bulk surface}} \times \text{Reaction rate}}$$

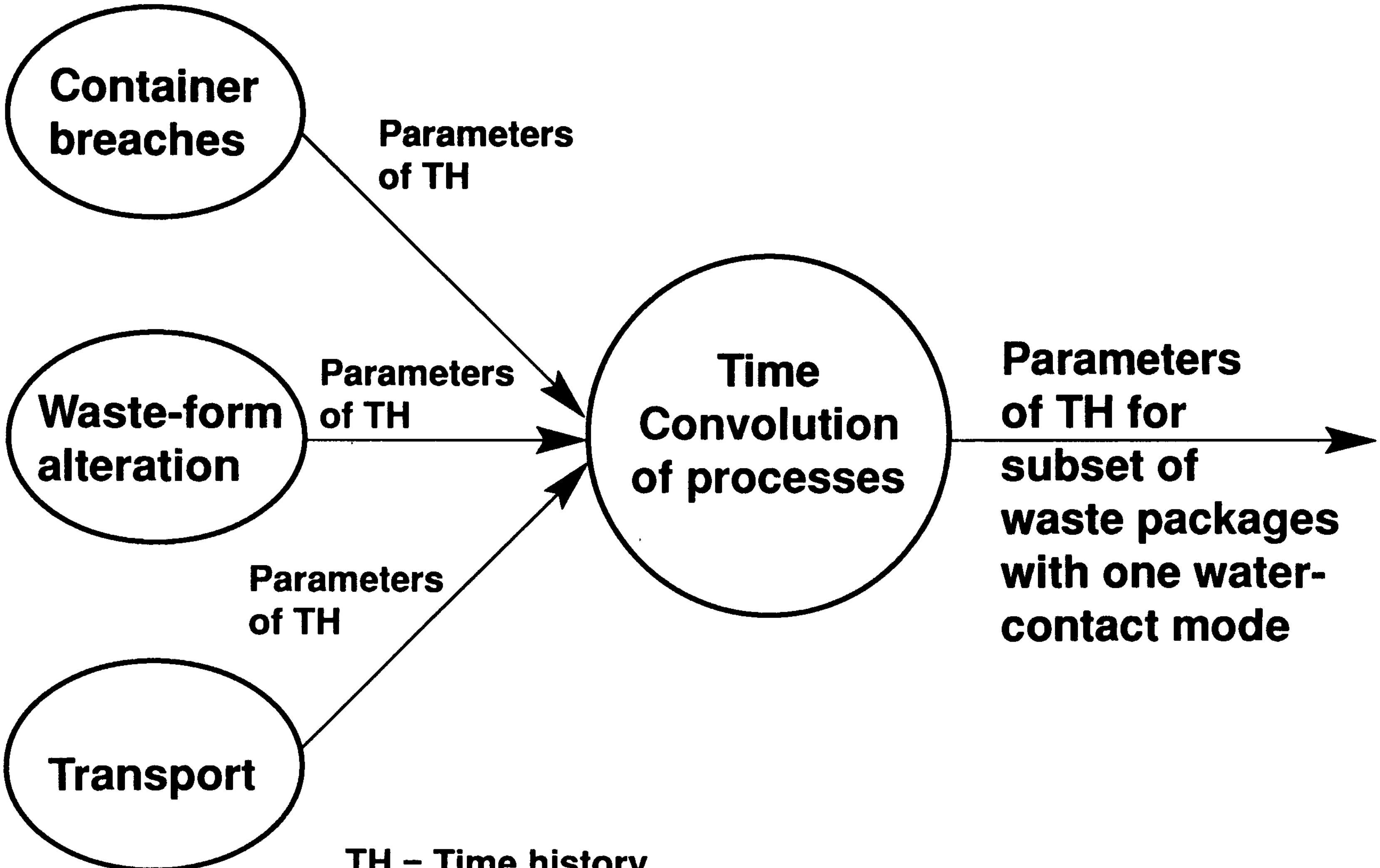
Organization of the Release Rate Calculation

- Top level
  - Radionuclide type
- Second level
  - Radionuclide location
- Third level
  - Water contact/transport mode
    * Diffusive moist
    * Diffusive wet plus advective in parallel
    * Advective, no diffusion
    * No liquid pathway

The Release-Rate Calculation is Grouped by Water-Contact mode



For Each Water-Contact Mode, the Release Rate TH Depends on Containers, on Waste Form/Geochemistry, and on Hydrology/Transport



TH = Time history

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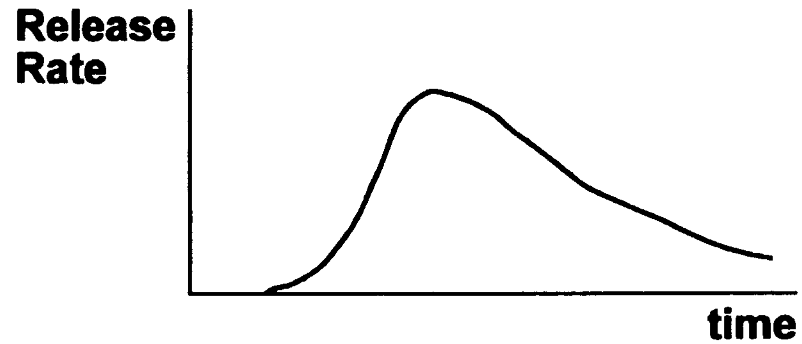
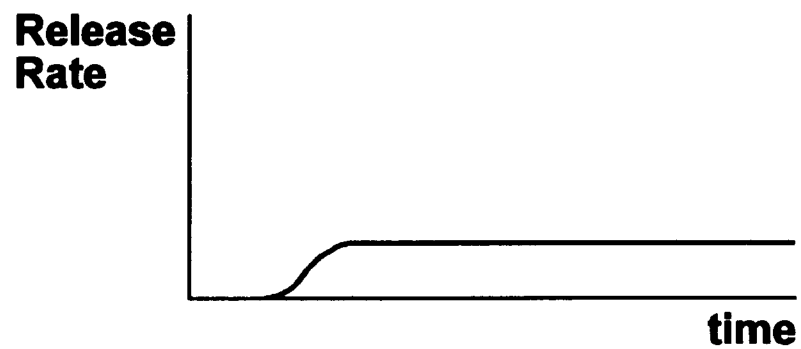
Earlier Work Found the Release-Rate Curves Had a Few Key Characteristics

For high-solubility radionuclides:



- Limited duration
- Peak value ~ 1 / duration

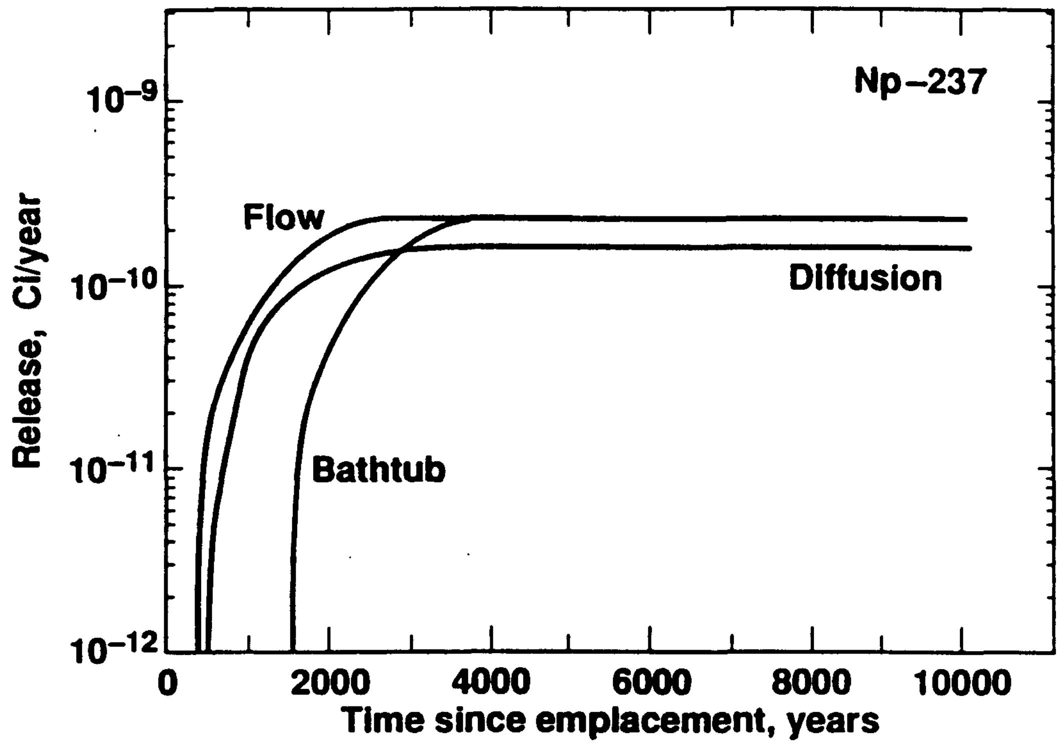
For low-solubility radionuclides:



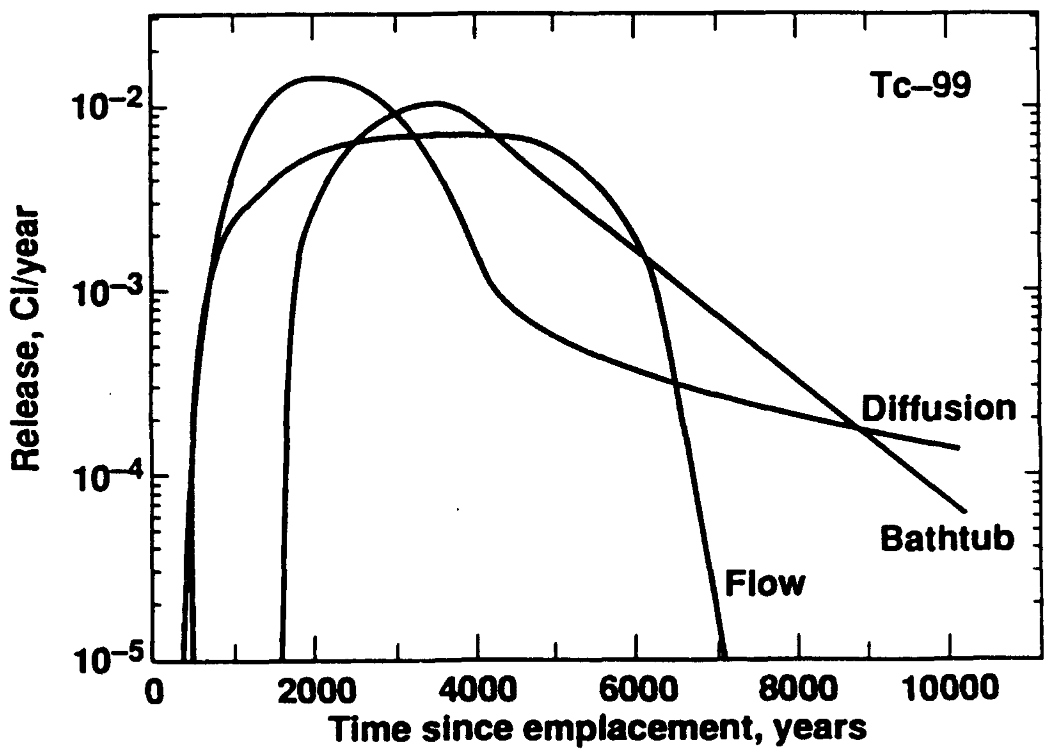
- Very long duration
- Constant plateau value

The simplified source-term model will calculate key parameters of the output curves.

Release of Low-Solubility Np-237 was of Low Amplitude, Long Duration

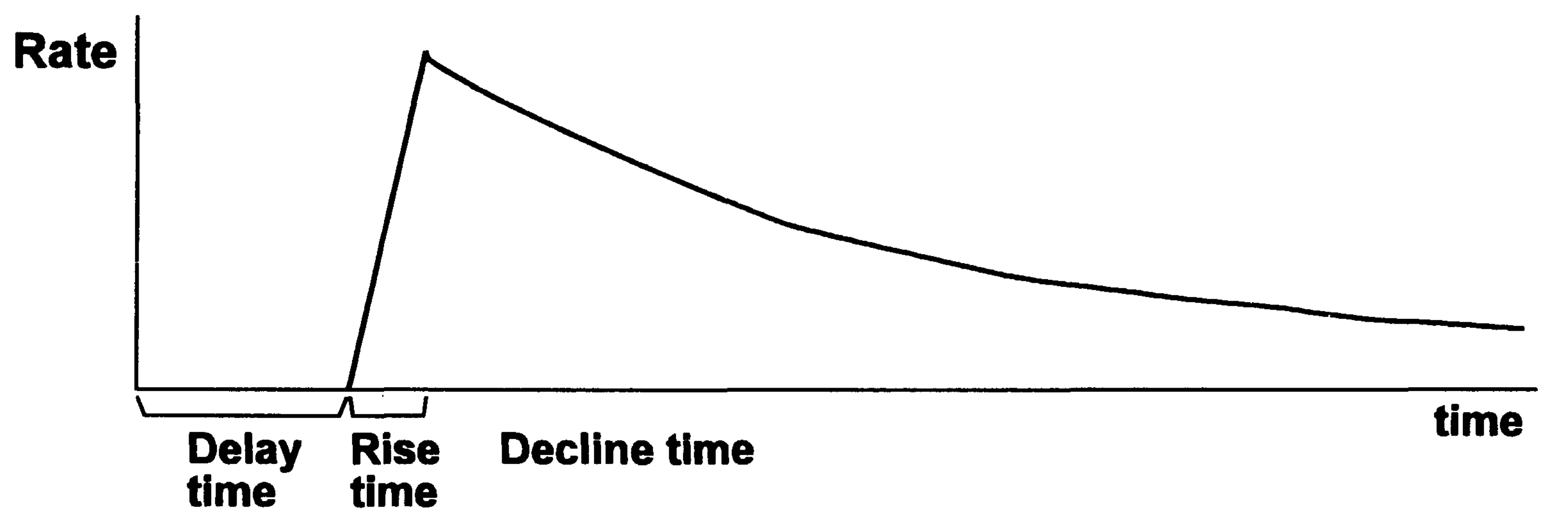


Release of Tc-99 from Wet Waste Packages was of Relatively Short Duration and High Amplitude



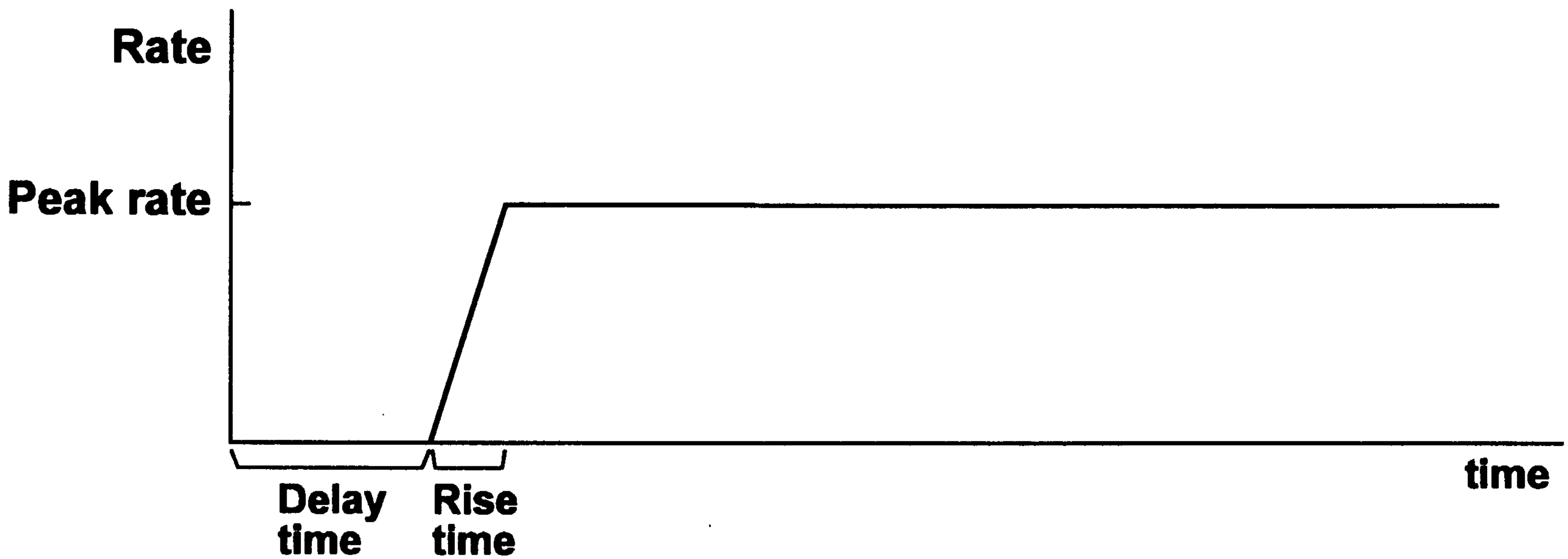
For Simplicity and for Focus on the First-Order Effects, Assumed a Generic Shape of the Time Histories

For highly soluble radionuclides:



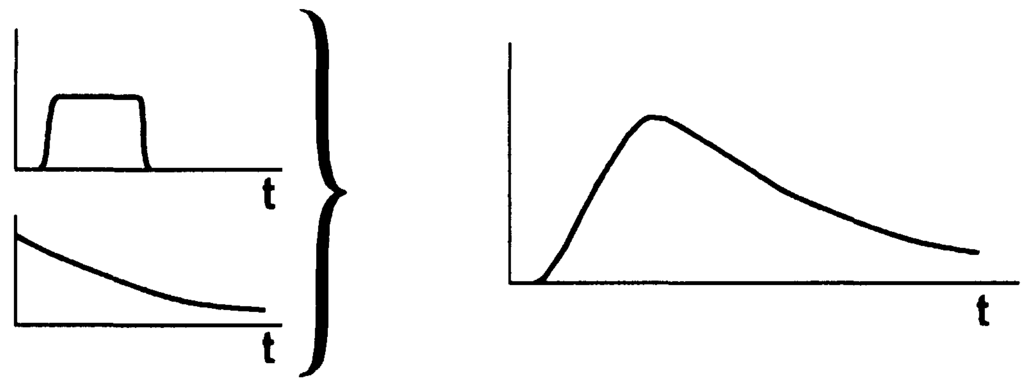
- Generic shape -- main effects only
- Parameters guided by sensitivity analysis
- Assume a time convolution gives same shape, new parameters

Shape for Solubility-Limited Radionuclides

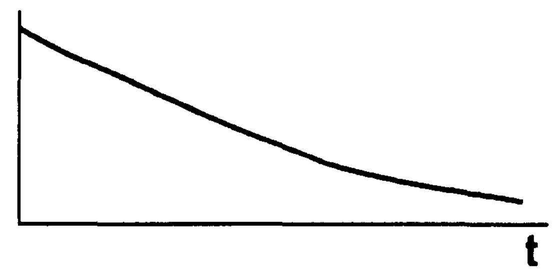


At the Center of the Release Model are the Single-Process Time Constants

Container breaches:
- Time spread in wetting
- Time spread in breaches after becoming wet



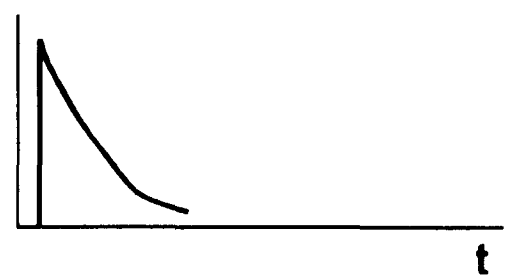
Waste form alteration:
- Characteristic time = 1 / Rate



Transport of a pulse:

Flowthrough: $t1 = \text{turnover time} = \dfrac{\text{Surface film volume}}{\text{Water influx/year}}$

(Use average value of advective water flux)



Key Uncertain Parameters

Total system hydrology:
- Average percolation flux
- Variance across the repository
- Saturated hydraulic conductivity of rock matrix

Waste package hydrology:
- Fraction of local advective flux getting into waste package
- Fraction of fuel surface wetted

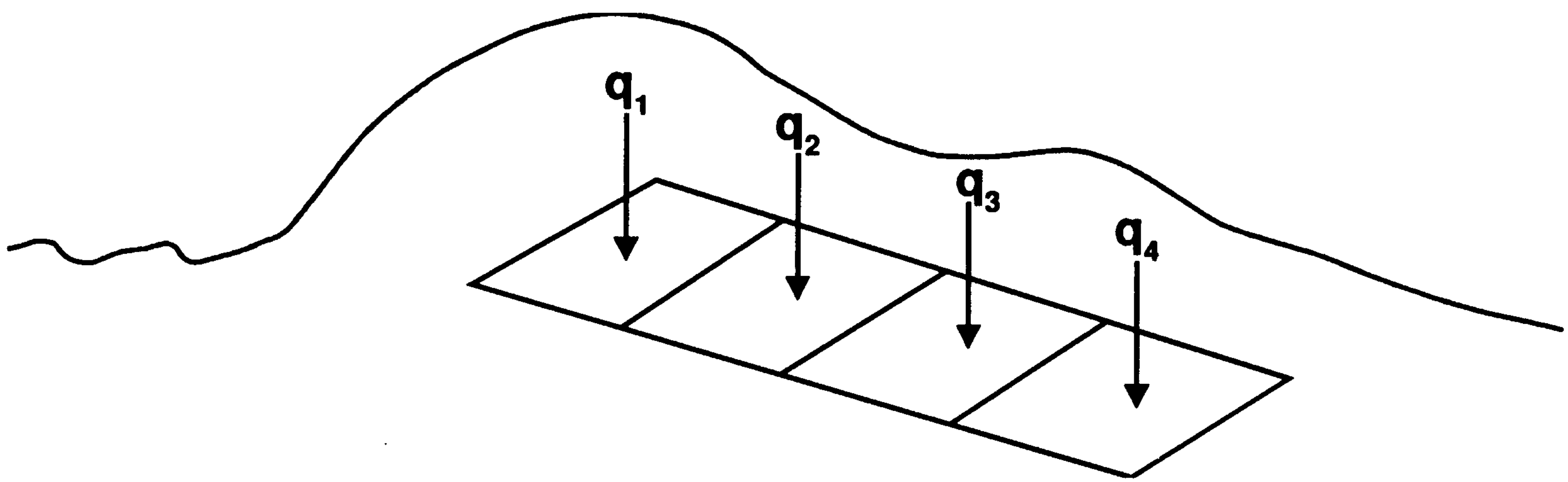
Rock mechanics:
- Fraction of boreholes with rubble
- Fraction of spent fuel exposed to diffusion

Diffusion hydrology and geochemistry:
- Effective diffusion coefficients
- Retardation factors

Geochemistry/waste-form interaction
- Fuel matrix alteration rate
- Element solubilities

Containers:
- Container failure rate

Area-Averaged Water Flux Affects Both Source Term and Far-Field Transport -- Correlations



- A trend in average water flux will introduce a correlation of source term strength and transport speed, and a de-facto correlation of these with transport path length to the water table
- Geochemical trends would probably also yield correlated changes in processes, but this was not explicitly modeled

Impacts of Hydrological Spatial Variability While Assuming a Matrix Flow Model

Assumptions:

- Lognormal distribution in space for the water flux
- Local excess flux goes into seepage flux
- Random spatial distribution of rubble occurrence

Results:

- Even a few % of waste packages with seepage flux will contribute most of the source term

- Hydrology-induced correlations among:
  - Container breach
  - Radionuclide release rate
  - Groundwater travel time to the water table

Impacts of Hydrological Spatial Variability, While Assuming a Fracture-Flow Model

Assumptions:

- A set of flows distributed in space and in amplitude; non-flowing zones have moist rock
- Random spatial distribution of rubble occurrence

Results are qualitatively similar to the matrix-dominated case