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

NUCLEAR WASTE TECHNICAL REVIEW BOARD
FULL BOARD MEETING

SUBJECT: TSPA EVALUATIONS OF ALTERNATE THERMAL LOADS, WASTE PACKAGE DESIGNS, AND PERFORMANCE CRITERIA

PRESENTER: DR. ROBERT W. ANDREWS

PRESENTER'S TITLE AND ORGANIZATION: PERFORMANCE ASSESSMENT MANAGER
CRWMS M&O/INTERA
VIENNA, VIRGINIA

PRESENTER'S TELEPHONE NUMBER: (703) 204-8849

ARLINGTON, VIRGINIA
JANUARY 12, 1994

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Total System Performance Assessment: Outline

- General objectives
- General approach
- Results
  - Thermo-hydrologic analyses
  - Waste package "failure"
  - Waste package release
  - Gaseous phase release
  - Aqueous phase release
  - Dose
- Summary
- Conclusions

General Objectives

- Enhance realism/representativeness of analyses
- Update analyses with new information
- Analyze effect of various design options
- Evaluate different measures of performance

Objective: Enhance Realism

- Directly incorporate process and parameter dependency on thermo-hydrologic environment
  - Initiation of aqueous corrosion
  - Aqueous pitting corrosion rates
  - Waste-form alteration and dissolution rates
  - Radionuclide solubility
  - Advective and diffusive release parameters

- Include defense high level waste and more complete radionuclide inventory

- Incorporate climate change

Objective: Incorporate New Information

- Solubility (function of temperature and geochemistry)
  - LANL
- Retardation coefficient (function of temperature and geochemistry)
  - LANL
- Waste-form alteration rate (function of temperature and geochemistry)
  - LLNL/PNL
- Gaseous-phase velocity (function of temperature)
  - SNL
- Saturated zone velocity
  - SNL

Objective: Analyze Alternate Designs

- Thermal load
  - 28.5 kW/Ac
  - 57 kW/Ac
  - 114 kW/Ac
- Waste package outer barrier thickness
  - 10 cm
  - 20 cm
  - 45 cm
- Waste package inner barrier thickness Alloy 825
  - 0.95 cm
  - 3.5 cm

Objective: Evaluate Alternate Performance Measures

- Cumulative release over 10,000 years
- Cumulative release over 100,000 years
- Individual dose over 1,000,000 years

General Approach

- Abstract primary functional relationships from detailed process models

- Define dependence of radionuclide exposure, waste-package release, and geosphere transport properties on primary variables

- Incorporate functional relationships and dependencies into the Repository Integration Program (RIP)

- Evaluate system performance and sensitivity

General Description of RIP

- Developed by Golder Associates, Inc.
- Uses the Monte Carlo method to propagate uncertainty to predict total system performance and its sensitivity
- Simplifies complex processes with analytical expressions of functional relationships and dependencies (i.e., abstractions)
- Allows inclusion of all relevant domains and processes affecting
  - Waste package/EBS release
  - Geosphere transport
  - Biosphere transport
  - Disruptive events

Representation of Waste Package/EBS Release

- Conduct panel-scale thermo-hydrologic analyses
- Determine delay in initiation of aqueous corrosion
- Calculate corrosion penetration depth
- Determine waste package "failure"
- Initiate waste-form alteration
- Calculate aqueous and gaseous release by diffusion and advection
  - Alteration-rate-controlled
  - Solubility-controlled

Representation of Geosphere Transport

- Carbon-14 transport derived from travel times in Ross (1993)
- Unsaturated zone aqueous transport assumes
  - One-dimensional equivalent continuum porous media
  - Matrix inbibition/matrix diffusion exceeds fracture transport
  - Exponential percolation flux distribution with mean = 0.5 mm/yr
  - Climate change represented by increasing/decreasing flux multiplier
- Saturated zone transport uses velocities from Barr (1993)
- Retardation based on elicited values from LANL

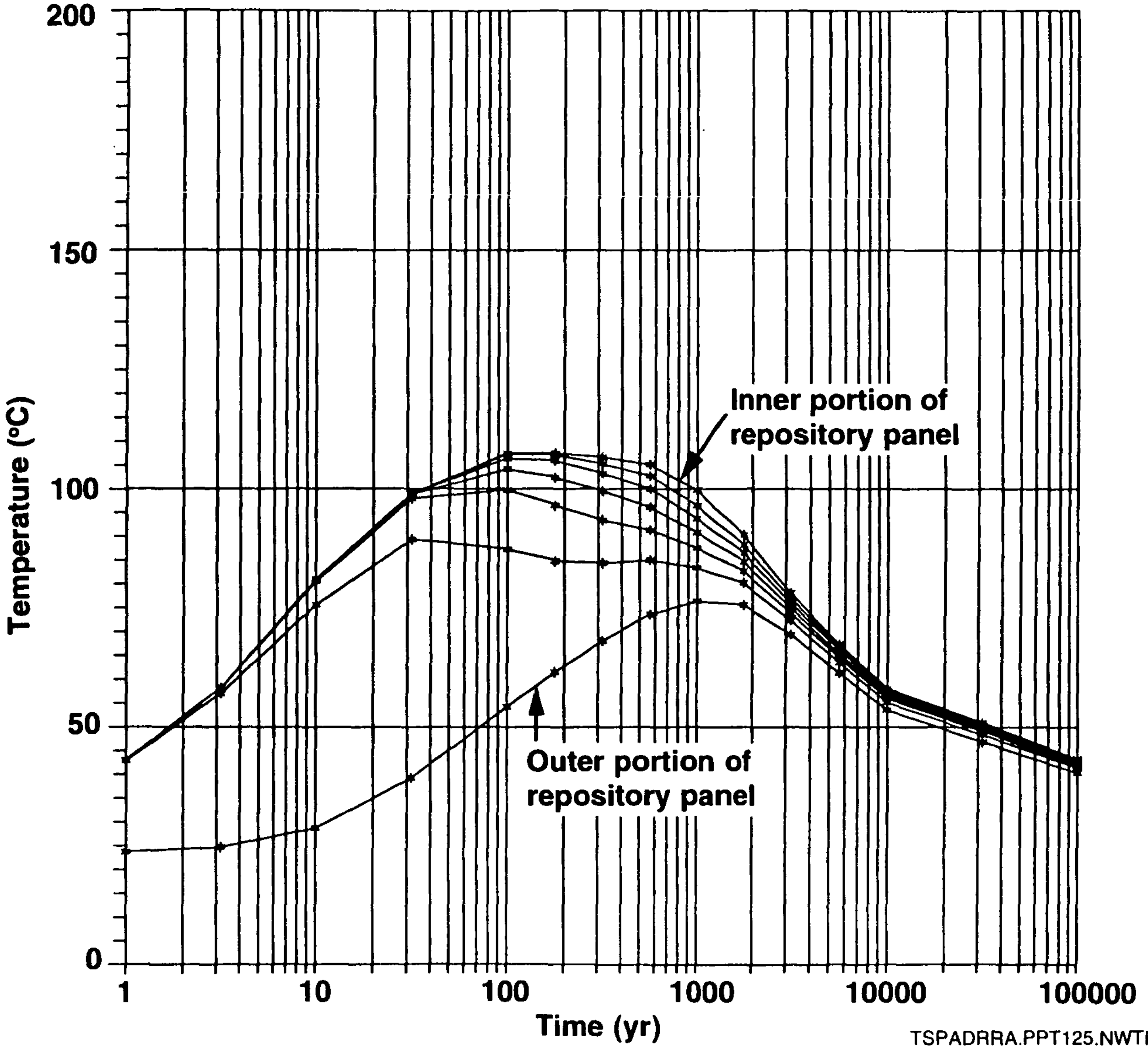
Representation of Biosphere

- Mass release at accessible environment is diluted by saturated zone flux
- Assume mixing depth of 50 m
- Dose determined using published dose-conversion factors used in TSPA-91

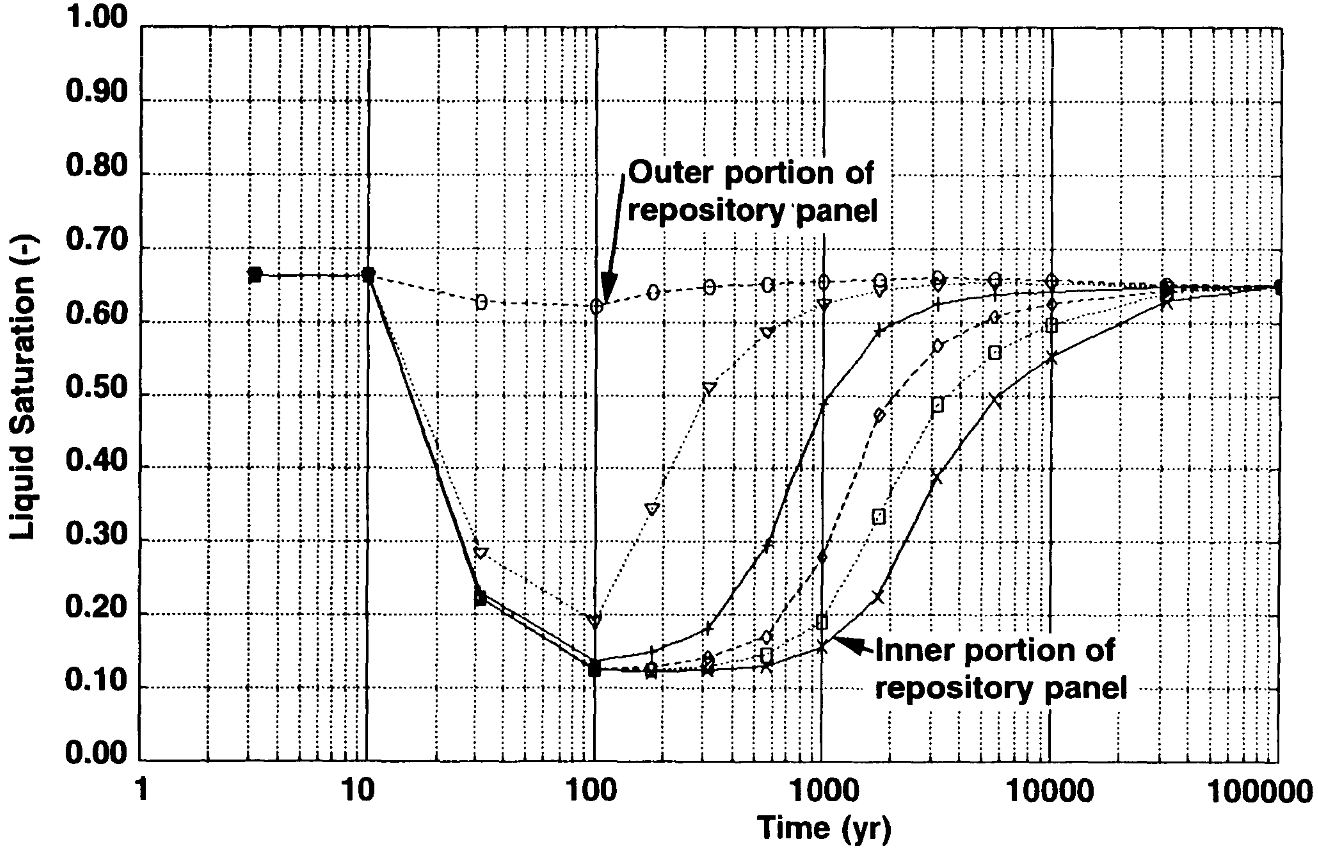
Results

- Thermo-hydrologic analyses
- Waste package "failure"
- Waste package release
- Accessible environment release
- Individual dose

Spatial and Temporal Panel-Scale Rock Temperatures at Repository Horizon for 57 kW/Ac



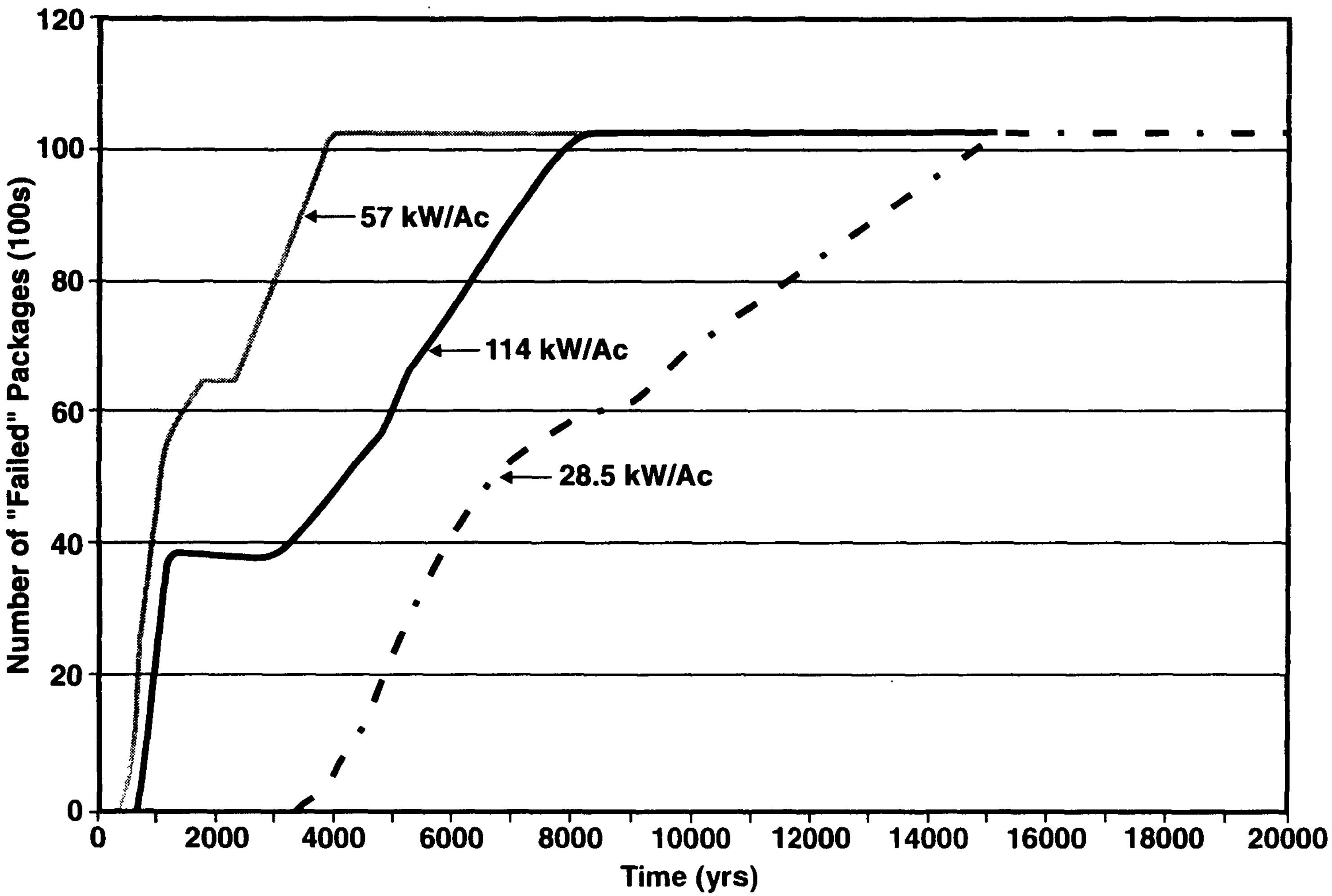
Spatial and Temporal Panel-Scale Liquid Saturations at the Repository Horizon for 57 kW/Ac



CDF of Waste Package "Failures": Sensitivity to Thermal Load

10 cm Outer Barrier, 0.95 cm Inner Barrier, Saturation Criterion for Corrosion Inititation
"Failure" = First Pit Penetrates Inner Barrier

7,000 SF
3,000 HLW



Waste Package Failure Time Ranges (a)(years)

Thermal Load kW/Ac	Corrosion Initiation Criterion	Outer Barrier Thickness 10 cm	20cm	45 cm
28.5	saturation	3,300 → 15,000	28,000 → 85,000	>100,000
	temperature	3,300 → 15,000	28,000 → 85,000	>100,000
57	saturation	500 → 4,000	2,600 → 24,000	59,000 → >100,000
	temperature	900 → 6,000	(b)	(b)
114	saturation	700 → 7,500	2,200 → 20,000	38,000 → >100,000
	temperature	4,900 → 20,000	(b)	(b)

(a) times are following closure and represent minimum and maximum of distribution
(b) no analyses conducted for these cases

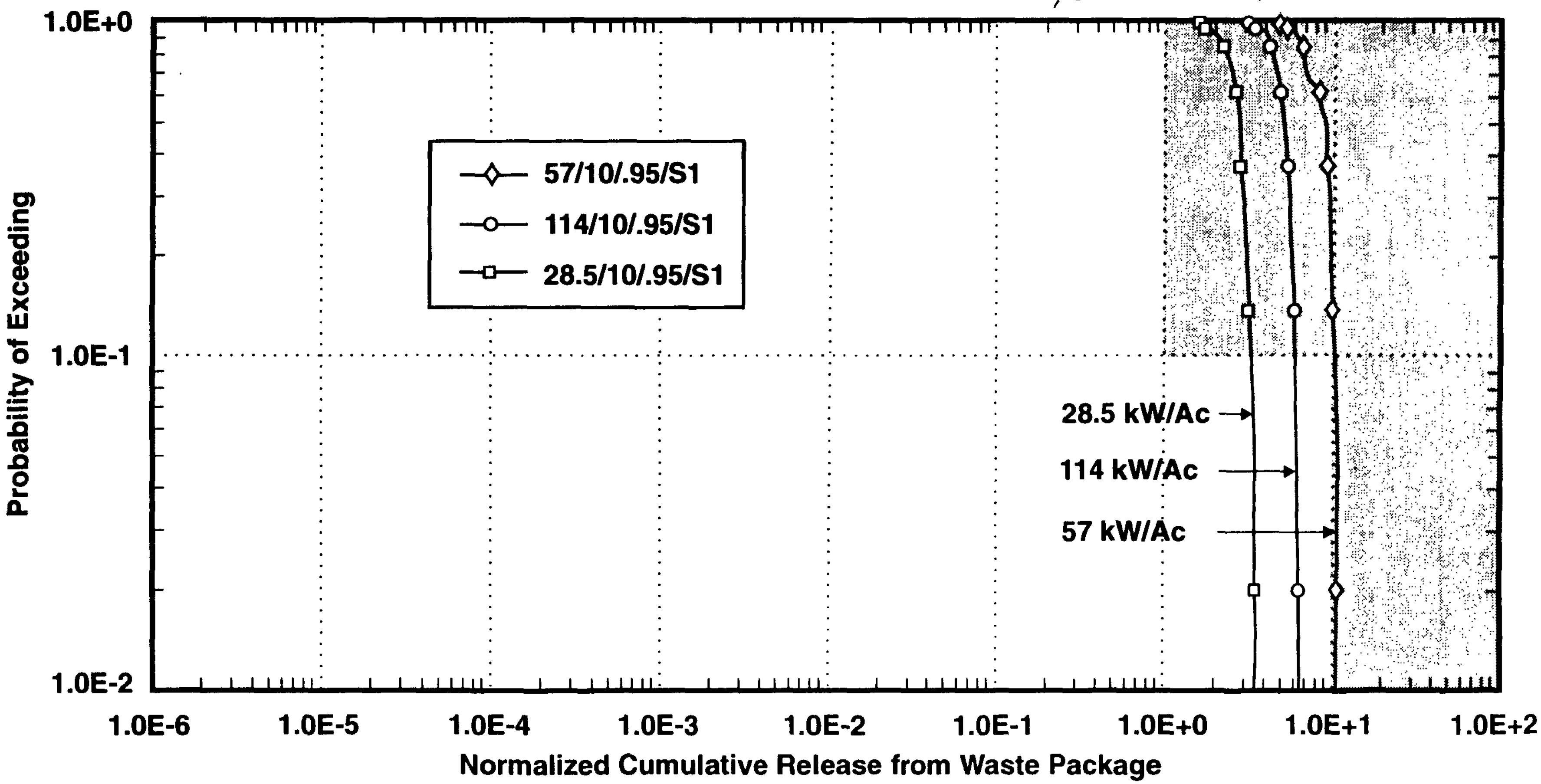
Summary of Waste-Package Failure Results

- Temperatures sufficiently low to preclude significant dry oxidation
- Delay in aqueous corrosion depends on thermal load, assumed corrosion initiation criterion, and location
- Aqueous corrosion rate depends on temperature (location and thermal load) and spatial variability
- The 57 kW/Ac thermal load yields more early failures than either the 28.5 kW/Ac or 114 kW/Ac case
- Conservatively assume no cathodic protection and cladding fails congruently

CCDF of 10,000 yr Total Normalized Cumulative Waste-Package Release: Sensitivity to Thermal Load

10 cm Outer; 0.95 cm Inner; Saturation Criterion for Corrosion Initiation

Dominated by C-14, but also Tc, I



Total Normalized Cumulative Releases from Waste Package over 10,000 Years

Thermal Load kW/Ac	Corrosion Initiation Criterion	Outer Barrier Thickness 10 cm	20cm	45 cm
28.5	saturation	2.9	0.0	0.0
	temperature	2.9	0.0	0.0
57	saturation	9.3	4.3	0.0
	temperature	7.1	(a)	(a)
114	saturation	5.5	2.0	0.0
	temperature	1.1	(a)	(a)

(a) no analyses conducted for these cases

Total Normalized Cumulative Releases from Waste Packages over 100,000 Years

Thermal Load kW/Ac	Corrosion Initiation Criterion	Outer Barrier Thickness 10 cm	20cm	45 cm
28.5	saturation	315	182	0.0
	temperature	315	182	0.0
57	saturation	383	369	29
	temperature	375	(a)	(a)
114	saturation	326	304	145
	temperature	301	(a)	(a)

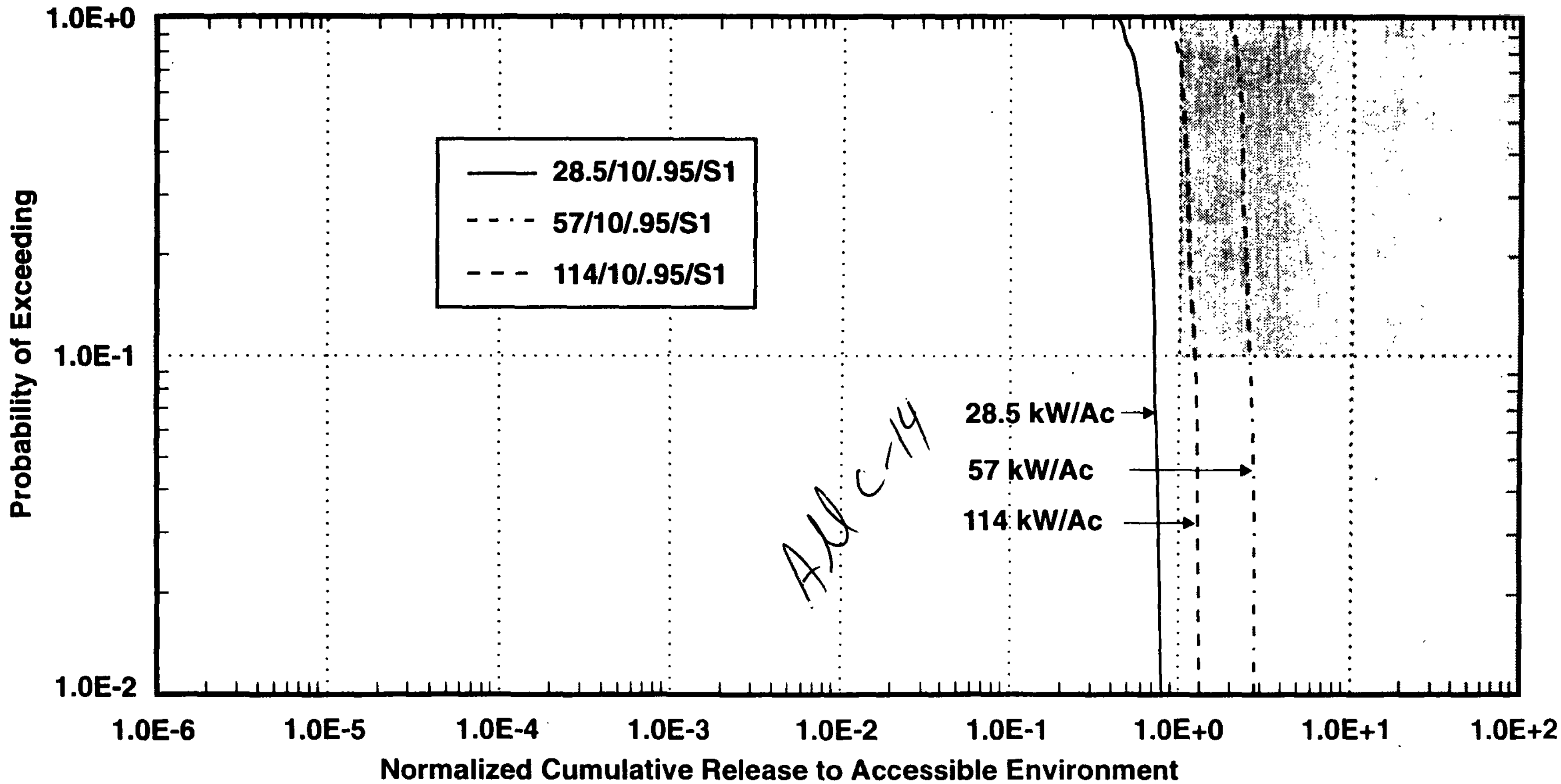
(a) no analyses conducted for these cases

Summary of Waste-Package Release Results

- Waste-package releases over 10,000 years are controlled by waste-package failure times and temperatures
- Principal radionuclides for 10,000 year release are ^{237}Np, ^{226}Ra, ^{14}C, ^{59}Ni, ^{99}Tc
- Principal radionuclides for 100,000 year release are ^{210}Pb, ^{227}Ac, ^{237}Np, ^{226}Ra, ^{14}C, ^{59}Ni, ^{99}Tc, ^{243}Am
- Normalized release from the waste package over 100,000 years is generally insensitive to thermal load and corrosion-initiation criterion
- Normalized release from the waste package is very sensitive to outer-barrier thickness

CCDF of 10,000 yr Total Normalized Cumulative Release to Accessible Environment: Sensitivity to Thermal Load

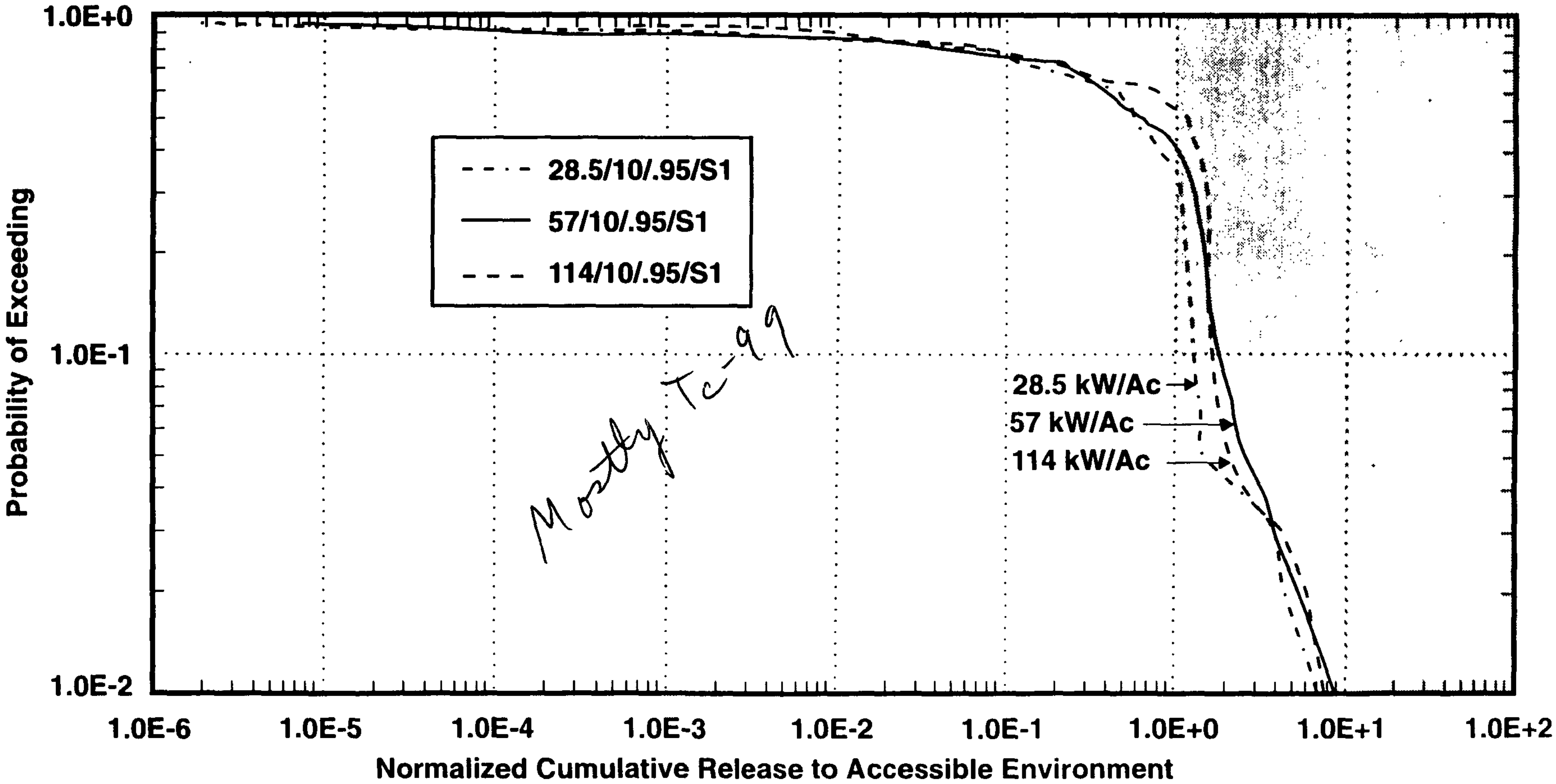
10 cm Outer; 0.95 cm Inner; Saturation Criterion for Corrosion Initiation



AMC-14

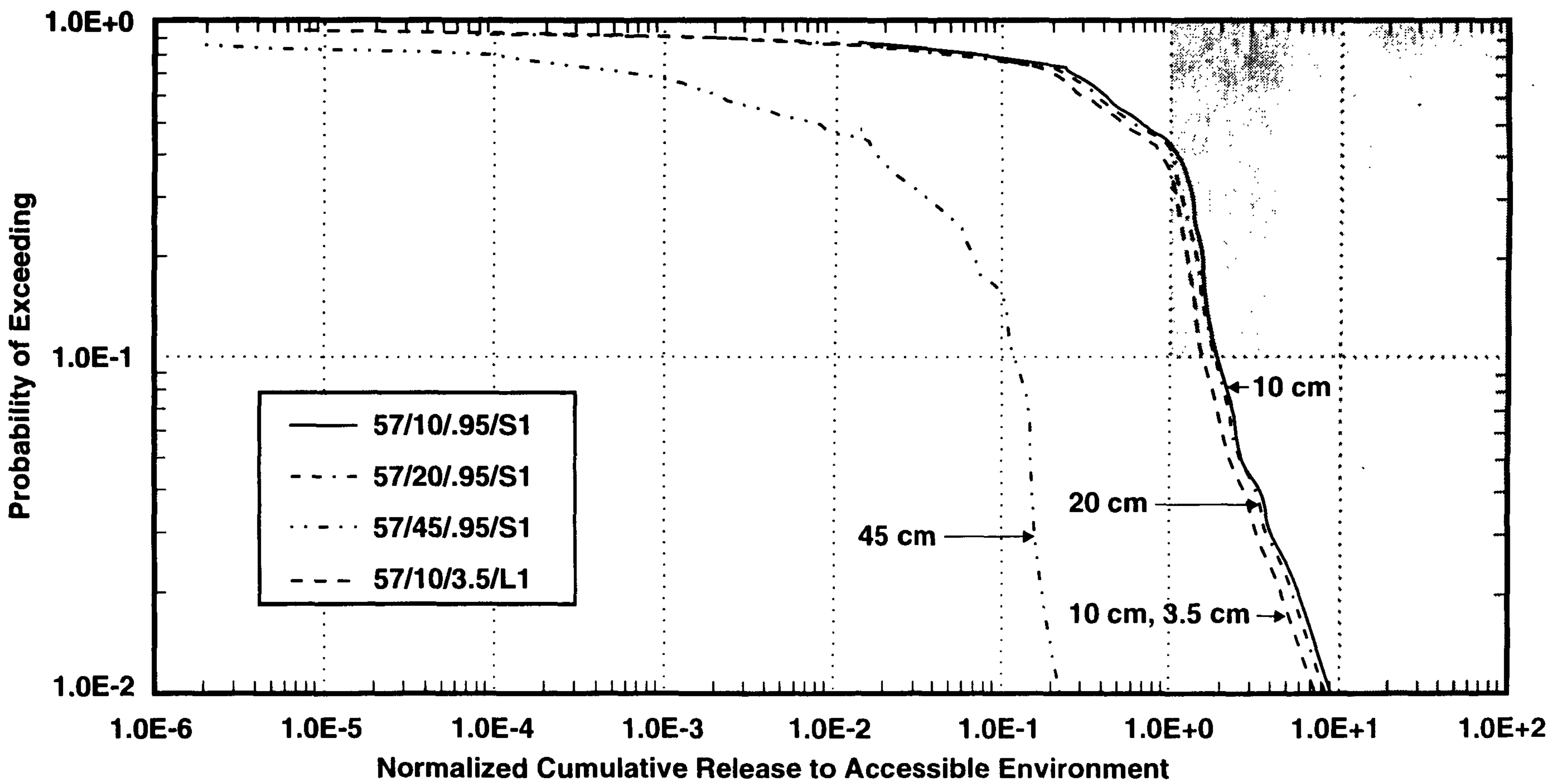
CCDF of 100,000 yr Normalized Cumulative Aqueous Release to Accessible Environment: Sensitivity to Thermal Load

10 cm Outer; 0.95 cm Inner; Saturation Criterion for Corrosion Initiation



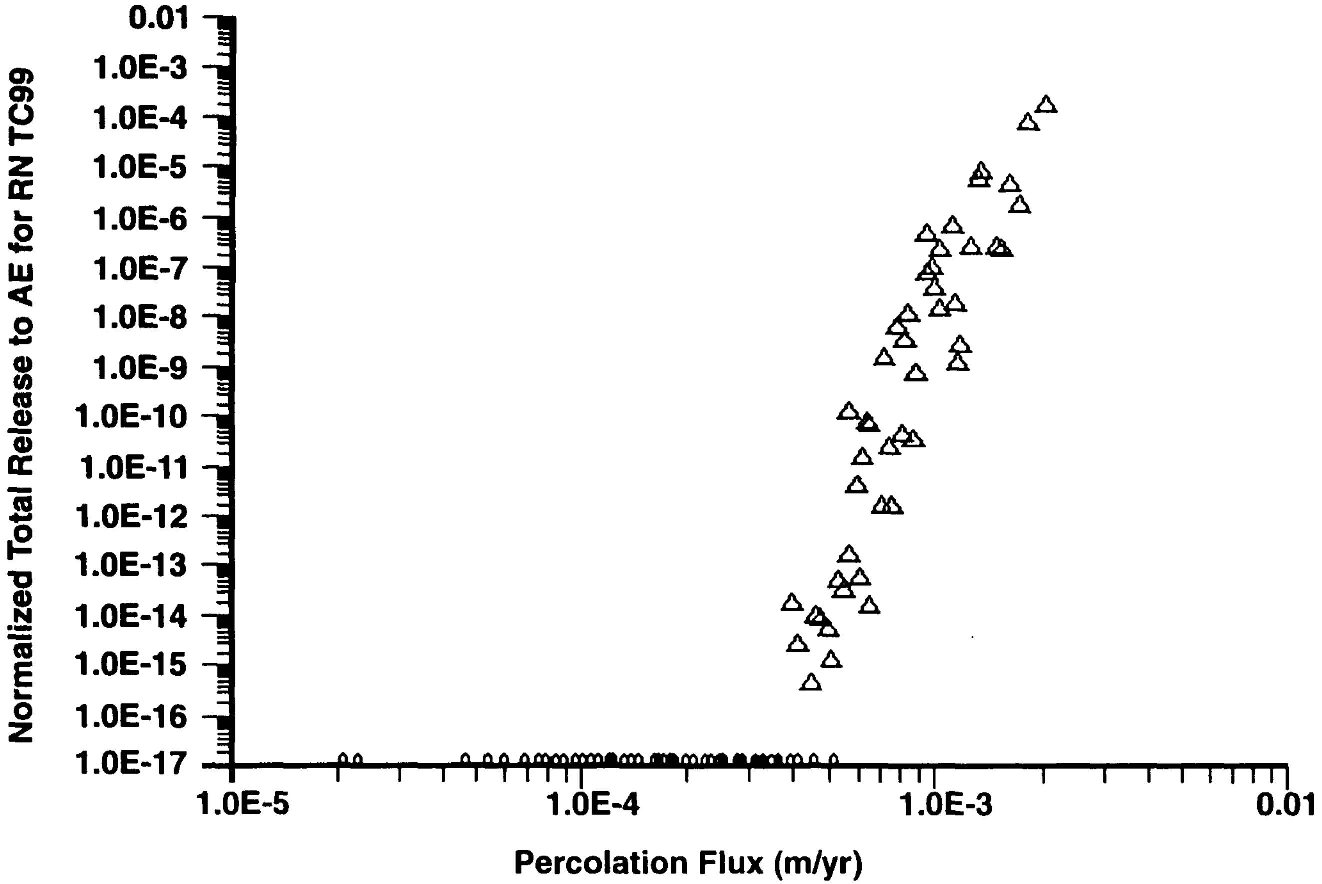
CCDF of 100,000 yr Normalized Cumulative Aqueous Release to Accessible Environment: Sensitivity to Thickness of Outer and Inner Barrier

57kW/Ac; Saturation Criterion for Corrosion Initiation



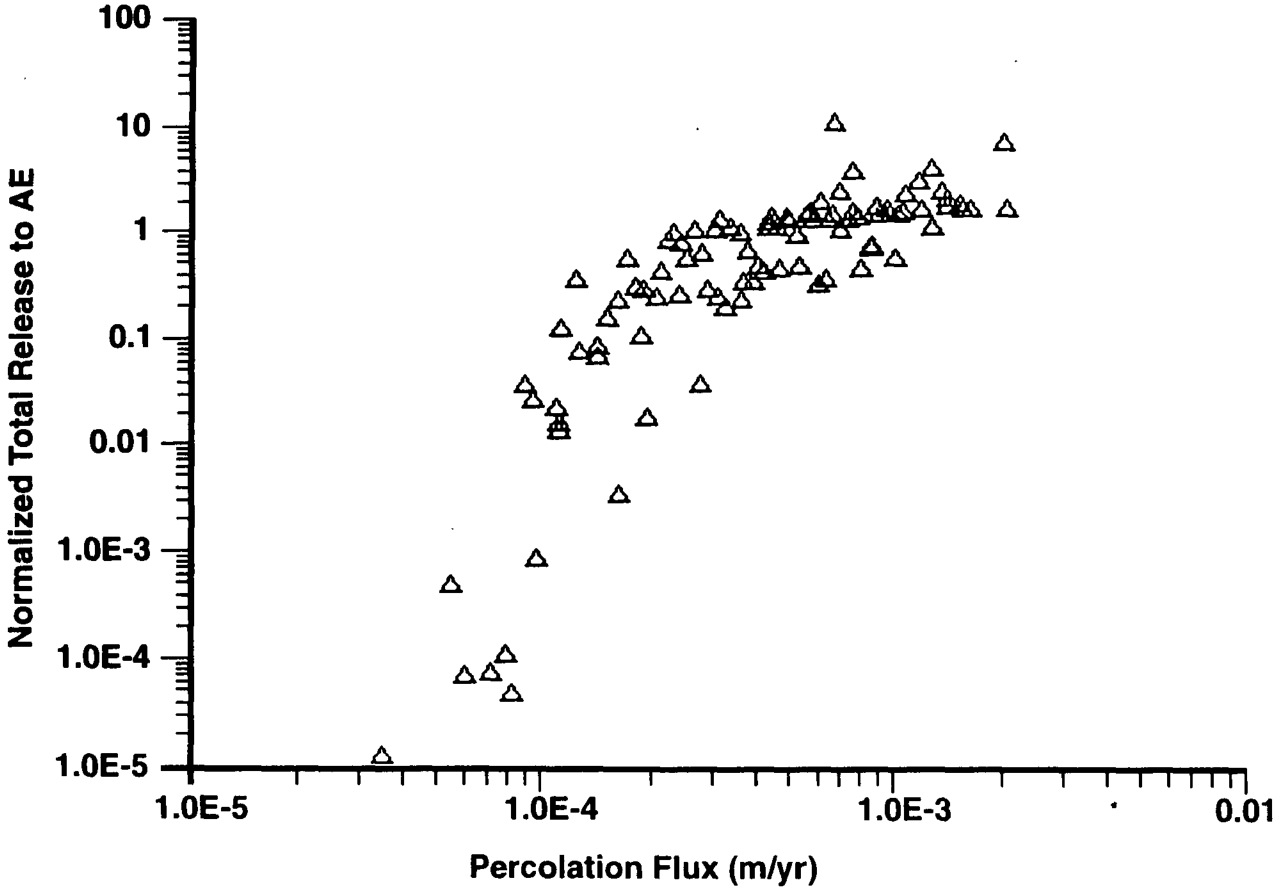
Sensitivity of 10,000 yr Normalized Cumulative ^{99}Tc Release to Percolation Flux

57 kW/Ac;10 cm Outer; 0.95 cm Inner; Saturation Criterion for Corrosion Initiation



Sensitivity of 100,000 yr Normalized Cumulative Aqueous Release to Percolation Flux

57 kW/Ac; 10 cm Outer; 0.95 cm Inner;
Saturation Criterion for Corrosion Initiation

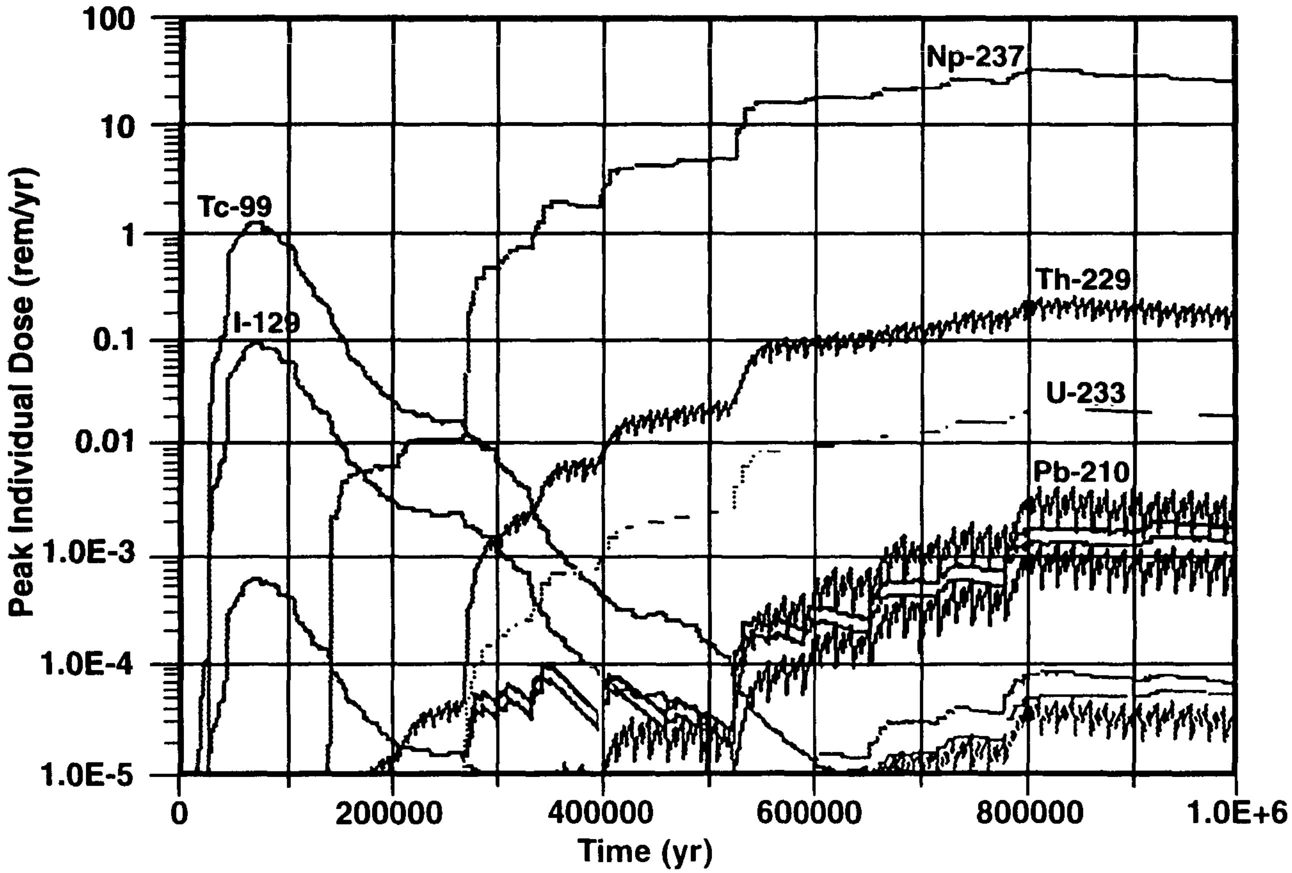


Summary of Releases to the Accessible Environment

- Normalized releases over 10,000 years are dominated by gaseous ^{14}C and therefore are controlled by waste-package failure time
- Normalized aqueous releases over 10,000 years have about 10% probability of exceeding 10^{-6} of Table 1 values (^{99}Tc)
- Normalized releases over 100,000 years are dominated by ^{14}C (about 60%) and ^{99}Tc (about 25%)
- Normalized releases over 100,000 years are generally insensitive to thermal load and waste-package thicknesses less than about 20 cm
- Normalized aqueous releases are controlled by the percolation flux

1,000,000 yr Peak* Individual Dose: Expected Value

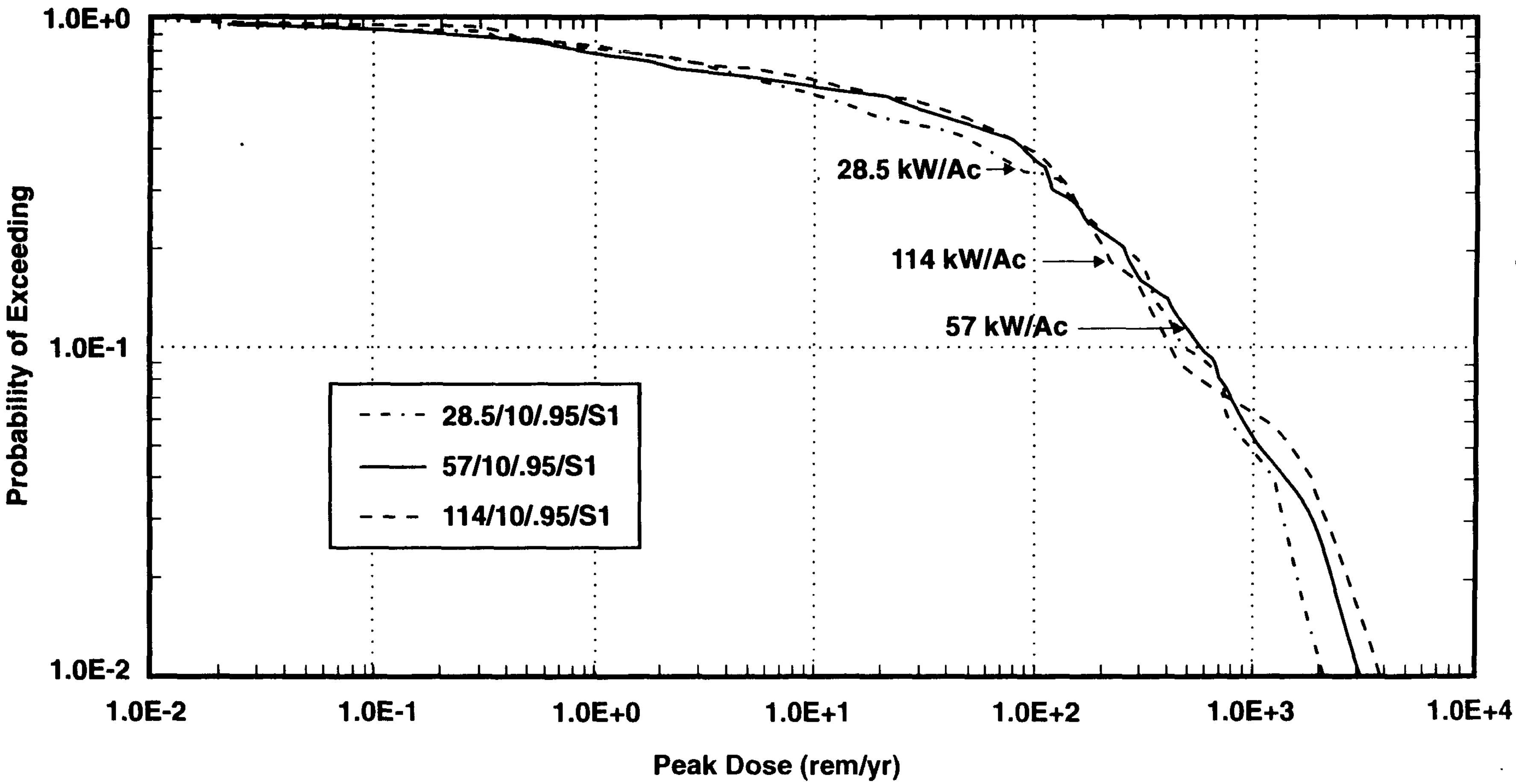
57 kW/Ac; 10 cm Outer; 0.95 cm Inner; Saturation Criterion for Corrosion Initiation



*** Maximally exposed individual**
Exposure from ingestion of water and irrigated crops

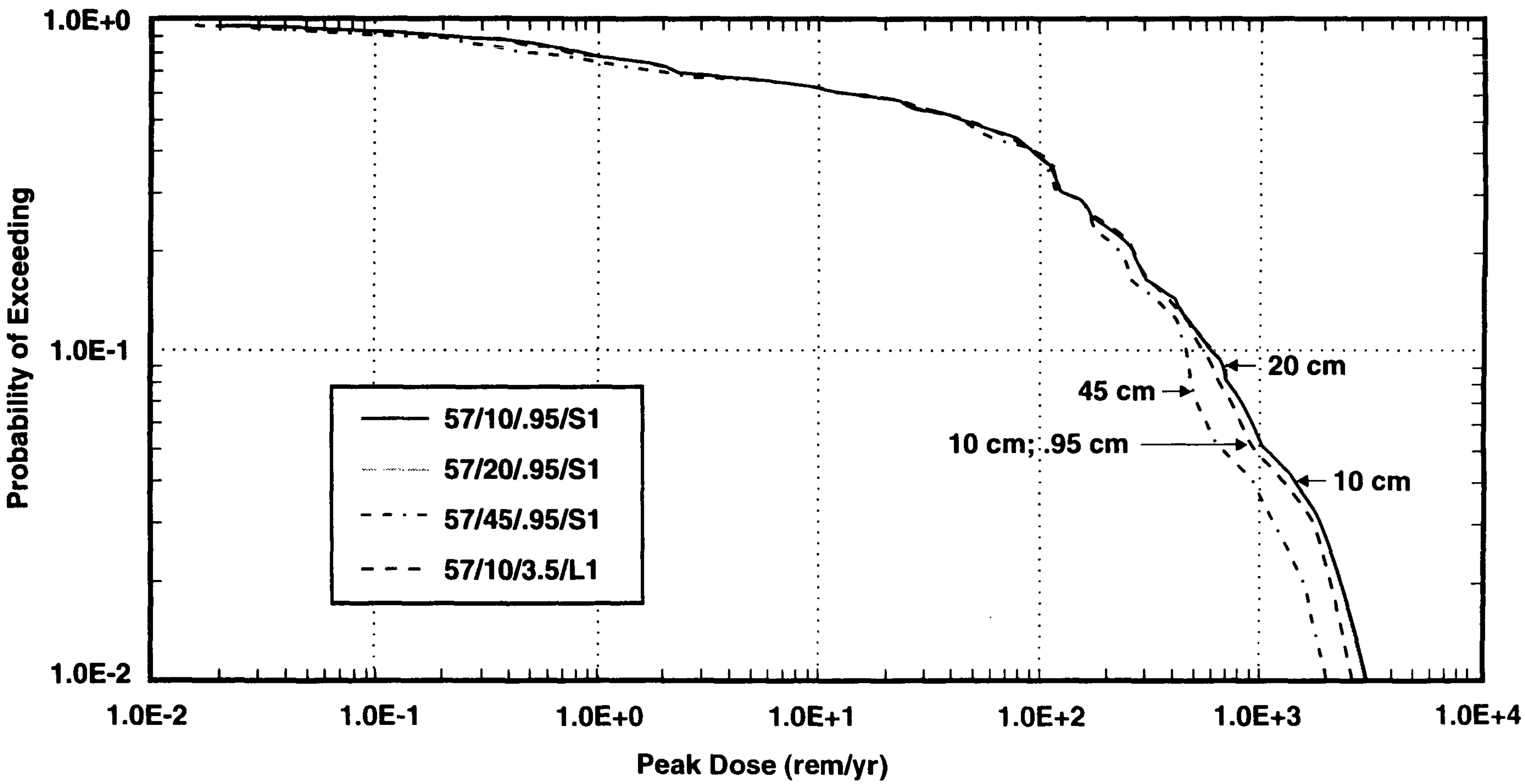
CCDF of 1,000,000 yr Peak Individual Dose: Sensitivity to Thermal Load

10 cm Outer; 0.95 cm Inner; Saturation Criterion for Corrosion Initiation



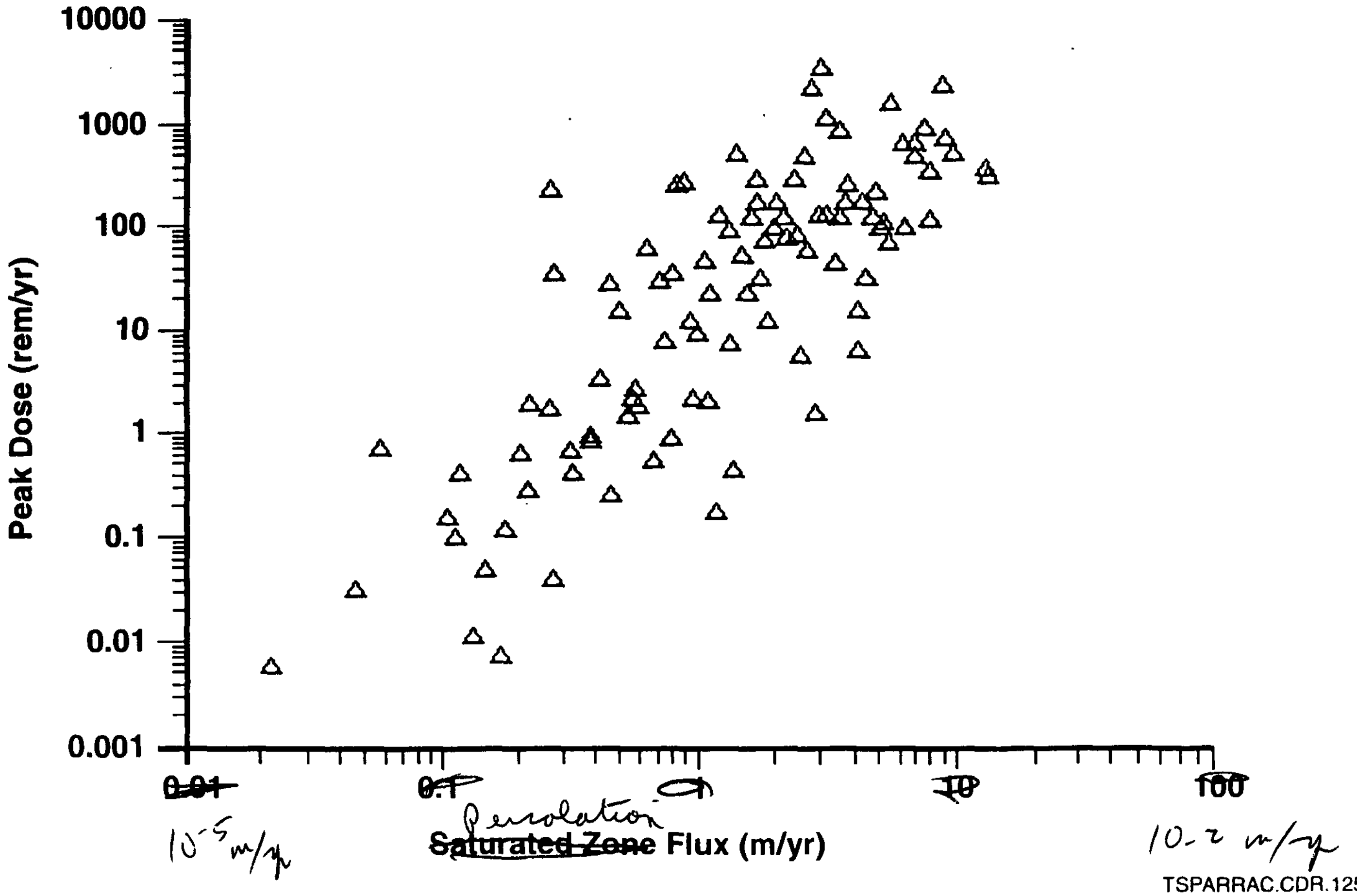
CCDF of 1,000,000 yr Peak Individual Dose: Sensitivity to Outer Barrier Thickness

57 kW/Ac; 0.95 cm Inner; Saturation Criterion for Corrosion Initiation



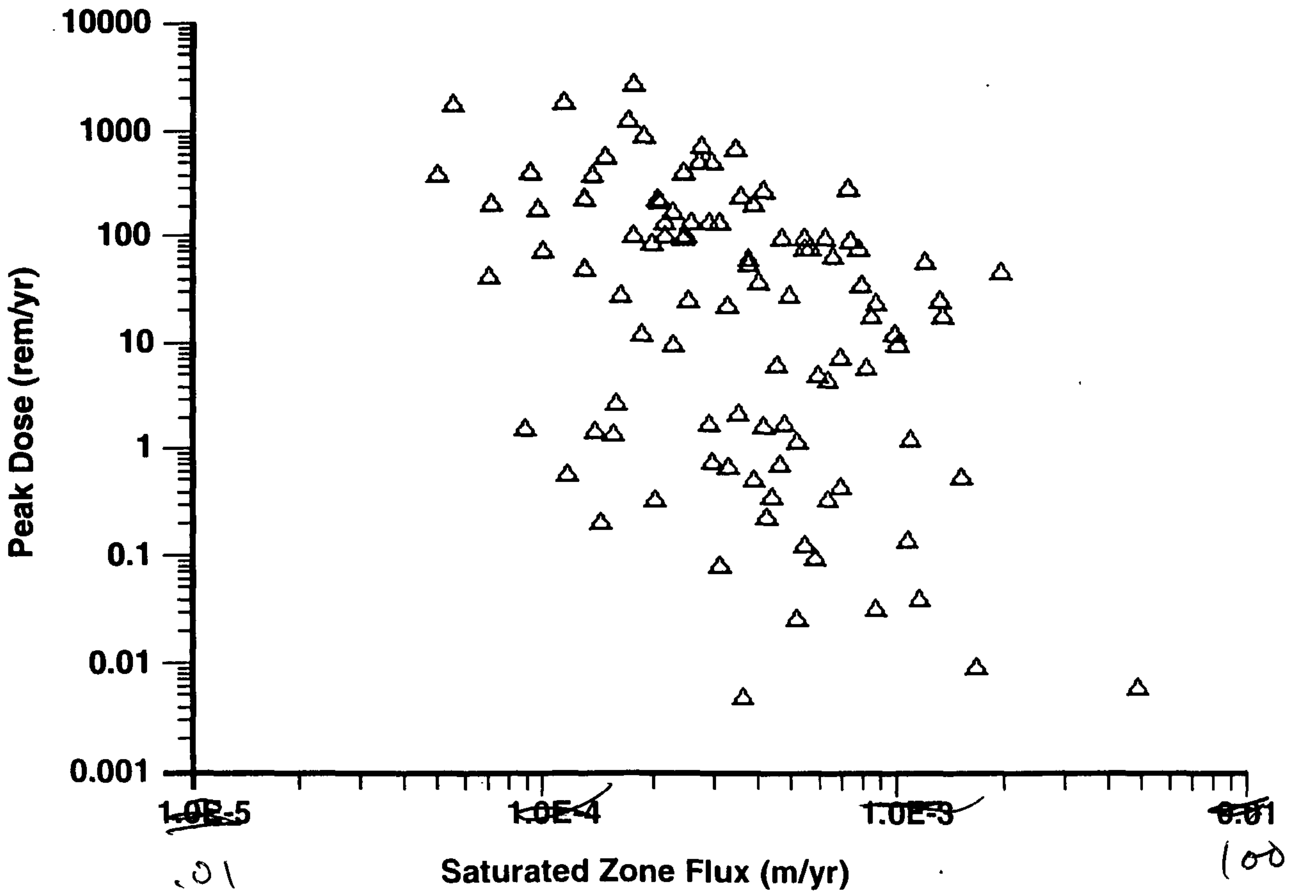
Sensitivity of 1,000,000 yr Peak Dose to Percolation Flux

57 kW/Ac; 10 cm Outer; 0.95 cm Inner; Saturation Criterion for Corrosion Initiation



Sensitivity of 1,000,000 yr Peak Dose to Saturated Zone Flux

57 kW/Ac; 10 cm Outer; 0.95 cm Inner; Saturation Criterion for Corrosion Initiation



Summary of Dose Results

- Long-term individual doses are dominated by ^{99}Tc over the first 200,000 years and by ^{237}Np for times greater than 200,000 years

- Peak doses are generally insensitive to thermal load and waste package design

- Peak doses are very sensitive to percolation flux and saturated zone flux

Summary of Results: Thermal Load Effect

- Integrated releases over 10,000 years are slightly sensitive to thermal loads; greatest for 57 kW/Ac; less for 114 kW/Ac due to delay of corrosion; less for 28.5 kW/Ac due to decrease in corrosion rates

- Peak dose for 1,000,000 years is insensitive to thermal load

Summary of Results: Waste Package Outer Barrier Thickness Effect

- Integrated releases over 10,000 years is not sensitive to thicknesses less than 20 cm; but for 45 cm waste packages, there is no release over 10,000 year

- Peak dose for 1,000,000 years is insensitive to waste package design

Significant Conclusions Based on TSPA-1993 Results

- Incorporation of more representative near-field thermo-hydrologic regime and dependencies had minimal effect on releases compared to TSPA-1991
- Inclusion of more complete inventory had minimal effect on cumulative releases compared to TSPA-1991
- Repository-level percolation flux and conceptual representation of matrix-fracture flow and transport remain as the most significant uncertainties affecting post-closure performance
- Over the ranges investigated, the matrix flow and transport properties show less sensitivity than the uncertain percolation fluxes, <u>but</u> these properties are important for understanding flow and transport through Yucca Mountain

Significant Uncertainties Remaining Following TSPA-1993

- Definition of very-near-field (drift-/waste package-scale) thermo-hydrologic environment

- Processes and parameters affecting the initiation and rate of aqueous corrosion including cathodic protection

- Aqueous percolation flux

- Conceptual representation of matrix-fracture transport in the unsaturated zone