YMP GEOLOGIC FRAMEWORK MODEL

The ISM series of models are constructed using the software program Earthvision Version 4 (CRWMS M&O 1998d).

The geologic framework from the Integrated Site Model version ISM2.0 (Clayton et al. 1997) is being updated with new data for delivery during FY1998 as ISM3.0 (in preparation). As a first step in this update, a geologic framework model was constructed in October-November 1997 as a test-bed for new data and new modeling software. This test-bed version is called ISM2.1. A cross section along the ECRB alignment through model both ISM2.0 and 2.1 this is shown in Figures O-1 and O-2, respectively. ISM2.1 will be documented in the ISM3.0 report.

The technical differences between ISM2.0 and 2.1 are due primarily to new data. The Site Area Geologic Map of Day et al. (1997) was digitally incorporated into ISM2.1, providing new geometric constraints and new interpretations of faults and geologic contacts. In addition, preliminary data, from an in-progress borehole re-evaluation being conducted by the USGS, were incorporated as inputs. ISM2.1 is considered non-qualified due to the use of the preliminary data and since the Earthvision Version used (Version 4.0) was not yet qualified at the time the model was constructed. However, because of the new data inputs, ISM2.1 is considered the best ISM version available at this time. The following discussion references ISM2.1.

Data constraints, which contribute to the accuracy of the cross section, include the geologic map for locations of faults and outcropping contacts, and lithostratigraphic data from boreholes. Spatial uncertainty increases with distance from these inputs (see Clayton et al. 1997). In the repository area near the cross section, vertical uncertainty for Topopah Spring Tuff contacts is on the order of plus or minus 25 feet (about 7 meters). It should be realized, however, that the boundaries of lithophysal/nonlithophysal zones within the Topopah are usually transitional and can vary vertically from place to place more than can be represented in the cross section.

West of the Solitario Canyon fault, the model cross section for ISM2.1 (Figure O-2) shows a geologic interpretation different from the USGS cross section (Plate 1). The differences are interpretive and are based on sparse data at this location (notice the tiny outcrop exposure of Tiva Canyon tuff west of the main fault). The three-dimensional model shows the rock units west of the Solitario Canyon fault dipping east, while the USGS interpretation shows the same units dipping west. The model's eastward dipping units are retrodeformable (i.e., the fault offset can be removed to restore the rock units to their original configuration as continuous sheets). The shallow outcrops of west-dipping Tiva Canyon Tuff may be part of a slump block which collapsed into the fault zone, but such detail is beyond the scope of the three-dimensional model.

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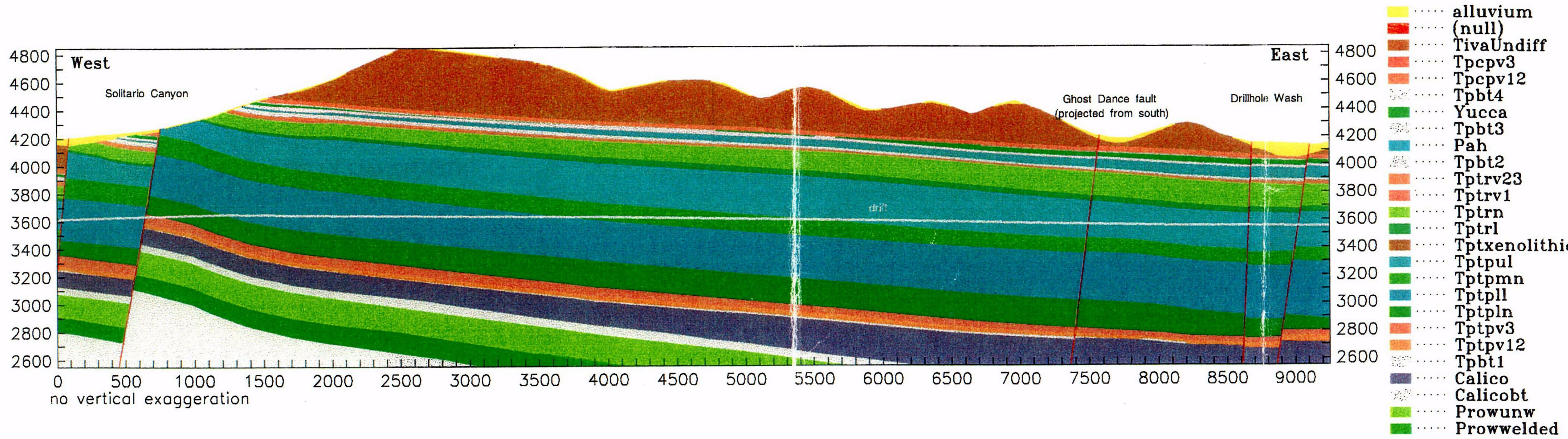
APPENDIX O

YMP GEOLOGIC FRAMEWORK MODEL



C-01

Figure O-1. Geologic Profile of the ECRB from Geologic Framework Model ISM 2.0

Note: Both vertical and horizontal scales in feet

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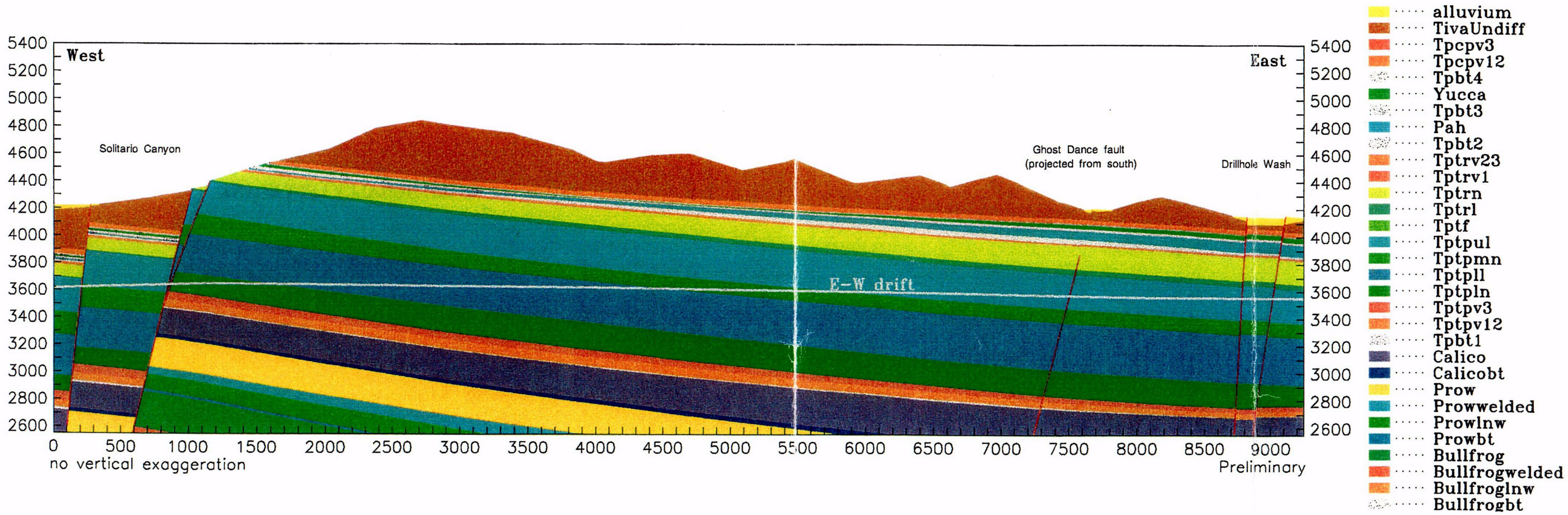

C-02

Note: Both vertical and horizontal scales in feet

Figure O-2. Geologic Profile of the ECRB from Geologic Framework Model ISM 2.1

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THIS PAGE IS AN OVERSIZED DRAWING OR FIGURE,

THAT CAN BE VIEWED AT THE RECORD TITLED:

GEOLOGIC MAP AND PREDICTIVE CROSS-SECTION ALONG THE CROSS-DRIFT ALIGNMENT, YUCCA MOUNTAIN, NYE COUNTY, NEVADA

WITHIN THIS PACKAGE

NOTE: Because of these page's large file size, it may be more convenient to copy the file to a local drive and use the Imaging (Wang) viewer, which can be accessed from the Programs/Accessories menu.

D-01

UNITED STATES
NUCLEAR WASTE TECHNICAL REVIEW BOARD
2300 Clarendon Boulevard, Suite 1300
Arlington, VA 22201-3367

Agenda

Panel on Performance Assessment: TSPA-VA

April 23-24, 1998

Sheraton Uptown Albuquerque Hotel
2600 Louisiana Blvd., NE
Albuquerque, New Mexico 87110
Tel: 505-881-0000
Fax: 505-881-3736

Thursday, April 23

8:00 a.m. **Welcome**
Daniel Bullen, Chair–Panel on Performance Assessment
Nuclear Waste Technical Review Board (NWTRB)

8:15 a.m. **Introduction to total system performance assessment for the viability assessment (TSPA-VA)**
Abe Van Luik, Department of Energy (DOE)

8:30 a.m. **Basic structure, conceptual model, and results of the TSPA-VA**
Robert Andrews, Management and operating contractor (M&O), INTERA
9:15*a.m.* *Questions/discussion*

10:00 a.m. **BREAK (15 minutes)**

10:15 a.m. **Uncertainty analysis in the TSPA-VA**
Michael Wilson, M&O (Sandia National Laboratories)
10:40 a.m. *Questions/discussion*

11:00 a.m. **Climate, infiltration, and unsaturated zone flow in the TSPA-VA**
Jack Gauthier, M&O (Sandia National Laboratories)
11:30 a.m. *Questions/discussion*

Telephone: 703-235-4473 Fax: 703-235-4495

Friday, April 24

8:00 a.m. **Reconvene: questions/comments from the public**

8:30 a.m. **Traceability example**
Cliff Ho, M&O (Sandia National Laboratories)
8:55 a.m. *Questions/discussion*

9:15 a.m. **Evaluation of disruptive scenarios**
Ralston Barnard, M&O (Sandia National Laboratories)
9:55 a.m. *Questions/discussion*

10:30 a.m. **BREAK (15 minutes)**

10:45 a.m. **Summary of TSPA-VA**
Holly Dockery, M&O (Sandia National Laboratories)
11:00 a.m. *Questions/discussion*

11:15 a.m. **Comments by the Nuclear Regulatory Commission**
Keith McConnell
11:30 a.m. *Questions/discussion*

11:45 a.m. **Summary comments**
Chris Whipple, ICF Kaiser Engineering
Jean Bahr, University of Wisconsin at Madison
Steve Frishman, Nevada Nuclear Waste Project Office
Robert Andrews, M&O (INTERA)

12:15 p.m. **Closing remarks and adjournment**
Daniel Bullen, NWTRB

YUCCA
MOUNTAIN
PROJECT

Studies

Introduction to Total System Performance Assessment for the Viability Assessment (TSPA-VA)

Presented to:
Nuclear Waste Technical Review Board
Panel on Performance Assessment

Presented by:
Dr. Abraham Van Luik
Senior Technical Advisor,
Assistant manager for Licensing
Yucca Mountain Site Characterization Office

April 23-24, 1998

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

Presentation Purpose

- To review recent Nuclear Waste Technical Review Board comments regarding the need for transparency in TSPAs
- To request the Nuclear Waste Technical Review Board's feedback at the end of this panel meeting
  - How well, in the presentations that follow, are these comments being addressed?
  - Are there specific suggestions for improving the TSPA process and its presentation?

Questions to be Asked of the TSPA-VA (and TSPA-LA)*

- **QUESTION 1: Does the TSPA demonstrate the safety of the repository?**
  - regulatory agencies emphasize demonstrating compliance with a standard using specific criteria
  - technical community will look at the validity of scientific and engineering assumptions
  - non-technical decision makers may be concerned about the political implications of a safety analysis
  - the public could judge the analysis on the sponsoring agency's reputation for honesty and openness
  - *Report to the U.S. Congress and the Secretary of Energy-1996, Findings and Recommendations, NWTRB, Mar.1997, p.21

Questions to be Asked of the TSPA-VA (and TSPA-LA)

(Continued)

- QUESTION 2: Does the TSPA generate confidence?
  - the ability of the TSPA to withstand challenges brought about by new knowledge and changing assumptions will be a prime factor in generating confidence in the conclusions
  - enhanced by the extent to which the analysis can be understood

Enhancing the Likelihood of Obtaining Positive Answers to the Two Questions

- Transparency - "the ease of understanding the process by which a study was carried out, which assumptions are driving the results, how they were arrived at, and the rigor of the analyses leading to the results"
  - if abstractions are fully understood, observers can develop a sense of confidence that the models are reasonable approximations of reality
  - specialist may require detailed knowledge of a model and its assumptions
  - non-technical decision maker or the public will want a conceptual explanation conveying what a model does, why that's important and how the results are interpreted
  - can be increased by well chosen sensitivity studies showing the effects of different assumptions

Enhancing the Likelihood of Obtaining Positive Answers to the Two Questions

(Continued)

- Proper Treatment of Uncertainty
  - different types of:
    - model uncertainty
    - parameter uncertainty
    - statistical uncertainty (randomness) inherent in natural processes
  - sensitivity studies can help show the significance of uncertainties
  - conservative assumptions
  - defensible uncertainty distributions

Enhancing the Likelihood of Obtaining Positive Answers to the Two Questions

(Continued)

- **Establishing validity using analogues and simplified calculations**
  - "a model is considered 'valid' if it provides a reasonably accurate representation of reality"
    - reasonable and accurate are potentially contentious words
    - "appropriate to the problem being addressed" is an important qualifier on these words
  - perform simple calculations capturing some of the main elements of the complete natural and engineering system to allow easier scrutiny of assumptions used in analysis

Enhancing the Likelihood of Obtaining Positive Answers to the Two Questions

(Continued)

- **Using outside expertise**
  - provides views not necessarily found within the DOE program for consideration
  - increases the program's technical credibility
  - should not substitute for scientific information reasonably available
- **Public acceptance**
  - likelihood of acceptance enhanced by transparency
  - increased public involvement urged
  - there are no simple or guaranteed ways of increasing public acceptance of an analysis for a project as technically complex and controversial as building a high-level waste repository

Summary

- In its Report to the U.S. Congress and the Secretary of Energy-1996, the NWTRB made suggestions regarding the need to increase the transparency of TSPAs
- The Department agrees with the intent of the Board's suggestions
- The Department invites your feedback on the presentations made at this Panel meeting, many of which reflect our continuing effort to address the Board's 'transparency' suggestions

YUCCA MOUNTAIN PROJECT

Studies

Basic Structure, Conceptual Model, and Results of the TSPA-VA

Presented to:
Nuclear Waste Technical Review Board
Performance Assessment Panel

Presented by:
Robert W. Andrews
Manager, Performance Assessment Operations
Duke Engineering and Services
Las Vegas, Nevada

April 23, 1998

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

Acknowledgements

TSPA Core Team:	S. David Sevougian, M&O/Duke Engineering Jerry McNeish, M&O/Duke Engineering Mike Wilson, M&O/Sandia Jack Gauthier, M&O/Sandia Ralston Barnard, M&O/Sandia Holly Dockery, M&O/Sandia
TSPA Analysts:	Vinod Vallikat, M&O/Duke Engineering Nelson Erb, M&O/Duke Engineering Patrick Mattie, M&O/Duke Engineering
TSPA Graphics	Kathy Gaither, M&O/Sandia Sharon Katsos, TRW BDM Interactive M&O Graphics Department

Outline

- Summary of Key Components in Natural and Engineered Systems
- Summary of Key Features of VA Reference Design
- Description of Significant Processes and Results of Key Components used in TSPA-VA Base Case
- Simplified Hand Calculation of Total System Performance

Methods to Present a Traceable and Transparent TSPA

- Identify all relevant processes for each key component that could impact long term performance
- Identify all the models that correspond to the key components and how these models are interconnected
- Identify the data in each model which forms the basis for each model
- Identify how the information flows from one component to the next in generating the total system behavior
- Explain all the results of each component and the total system in physical terms
- Produce a simple calculation of the system performance that elucidates the key aspects in the analyses

Postclosure Safety Strategy Attributes	TSPA Model Components
Water Contacting Waste Package	Climate Infiltration Unsaturated Zone Flow-Percolation Seepage Drips onto Waste Package Thermal Hydrology
Waste Package Lifetime	Near-Field Geochemical Environment Waste Package Degradation
Mobilization Rate of Radionuclides	Cladding Degradation Waste Form Degradation Seepage into Waste Package Colloid Formation and Stability Radionuclide Solubility Transport within Waste Package
Concentration of Radionuclides in ground water	EBS Transport Unsaturated Zone Transport Saturated Zone Transport Dilution from Pumping Biosphere

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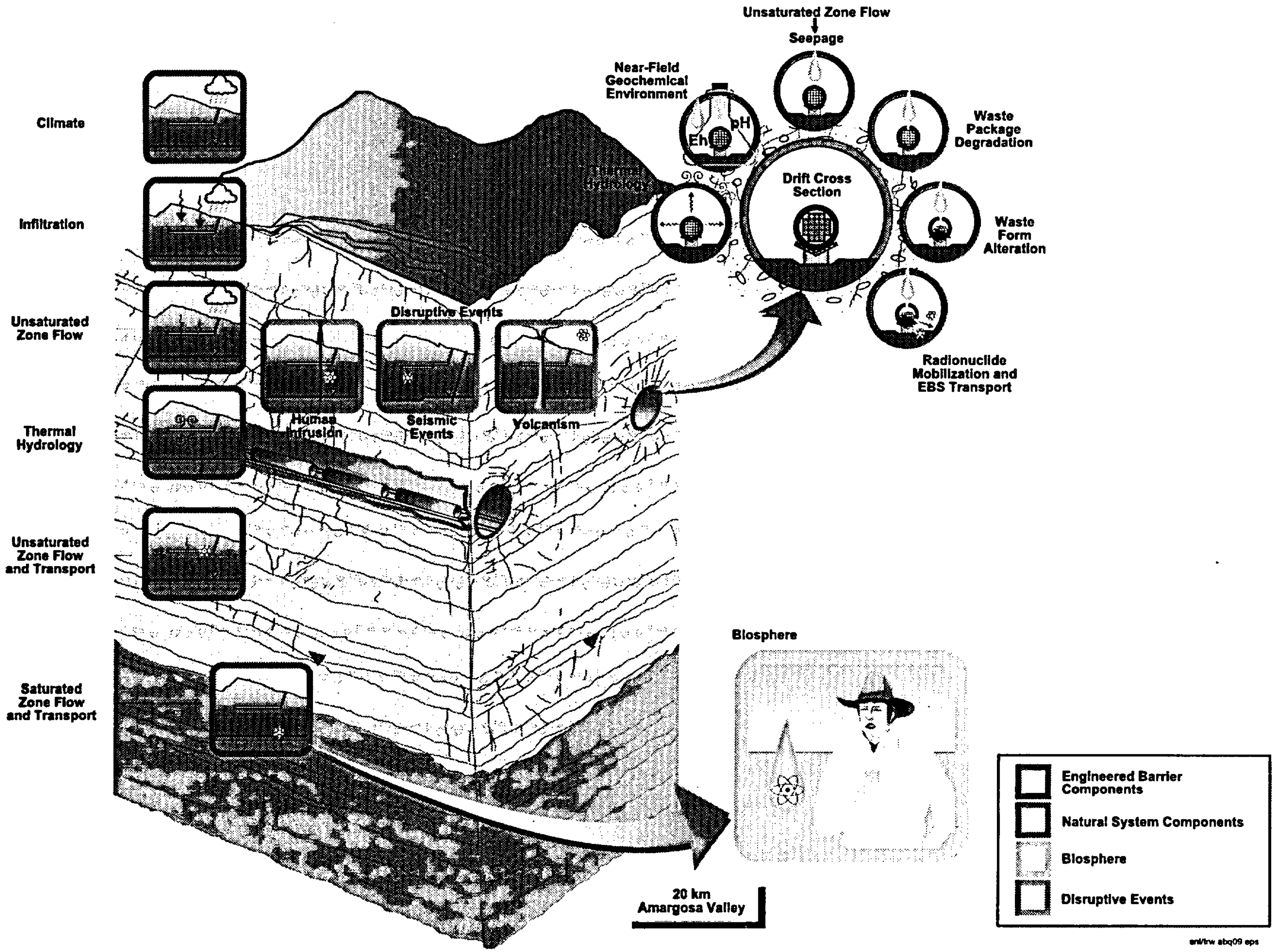
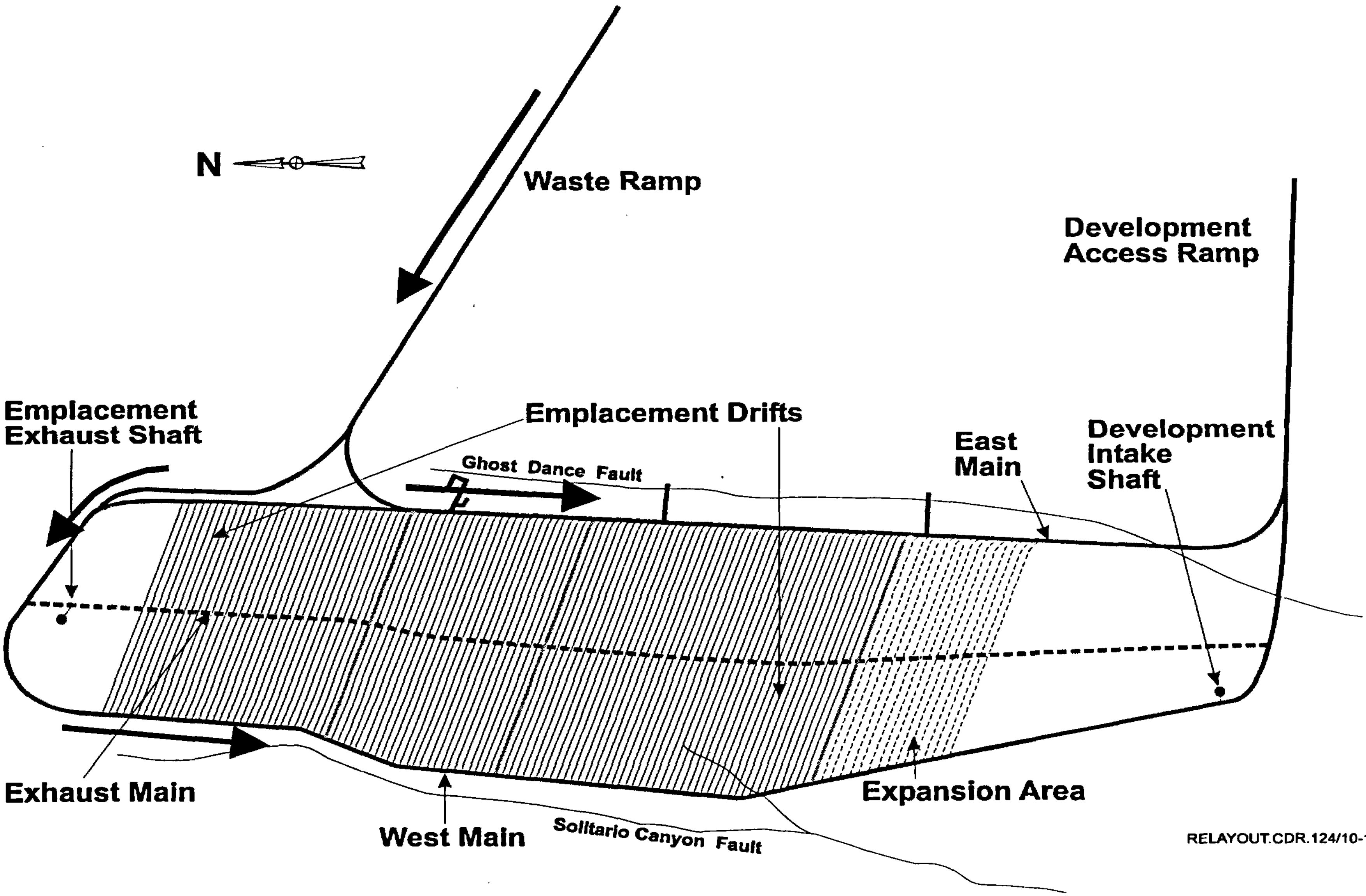
TSPA Model Components



Key Features of Reference Design for Viability Assessment: Repository

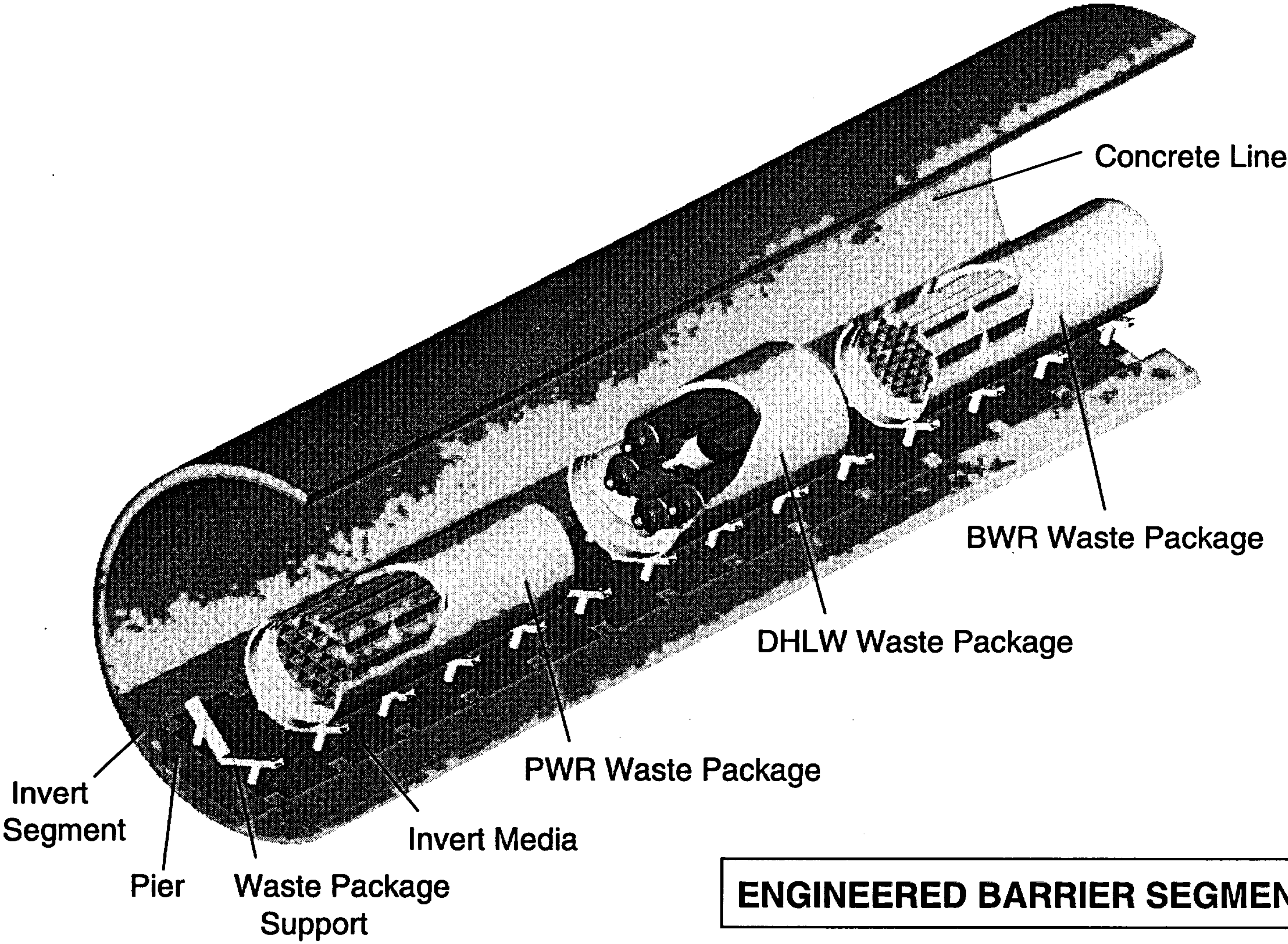
- ~300m depth; ~300m above water table
- Topopah Spring welded units
  34 - Middle nonlithophysal
  35 - Lower lithophysal
  36 - Lower nonlithophysal
- 85 MTHM/Acre
- 70,000 MTHM
  63,000 MTHM CSNF
  2,333 MTHM DOE-SNF
  4,667 MTHM HLW
  65 MTHM Navy Fuel
  50 MTHM Pu-MOX

Preliminary Repository Layout



Key Features of Reference Design for Viability Assessment: Engineered Barrier/Emplacement Drift

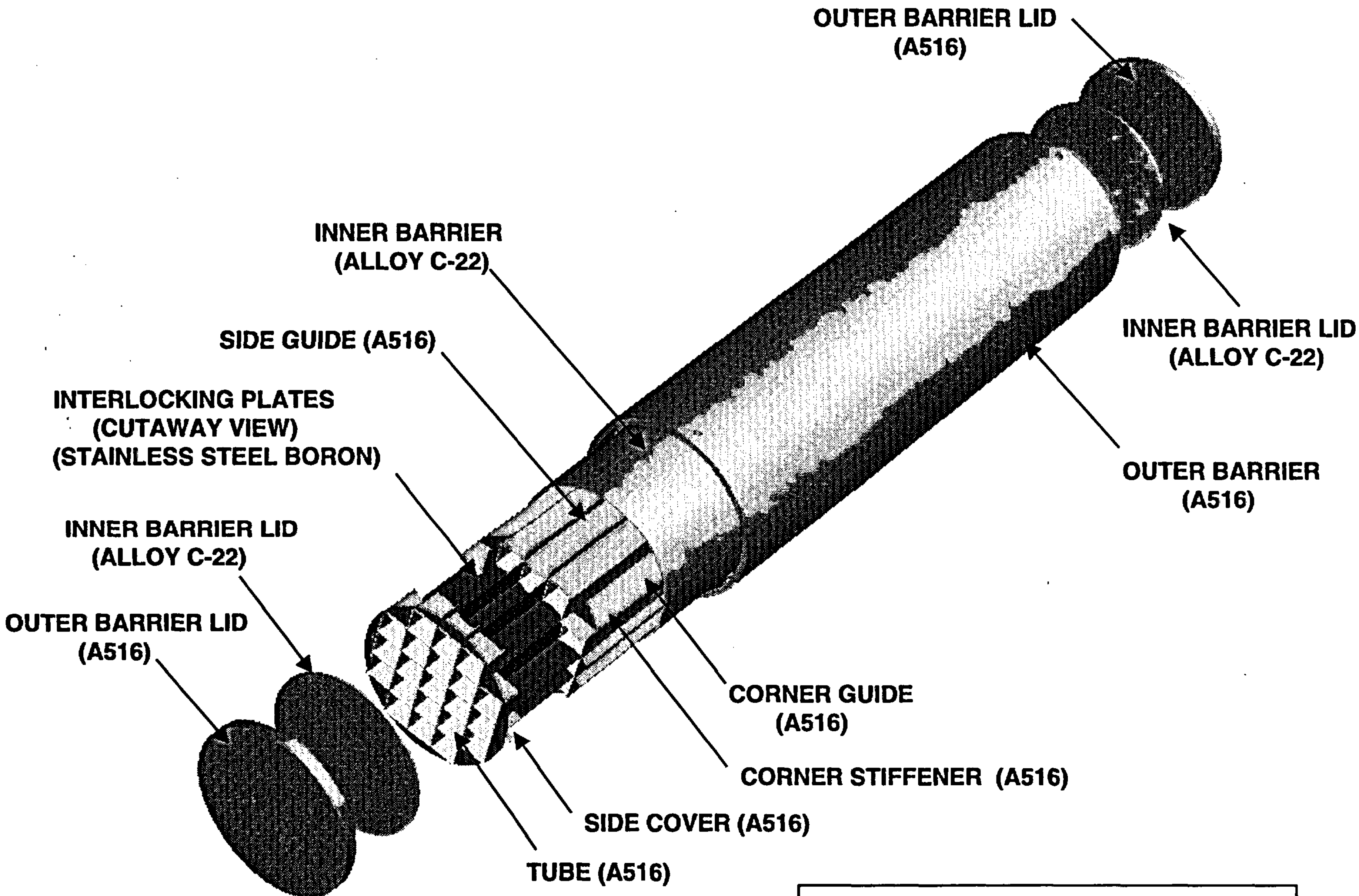
- 5.5m - diameter drift
- 20cm concrete liner
- Waste Packages placed on mild steel supports on concrete invert
- Waste Package spacing ~5m (point load)
- No backfill or drip shields



ENGINEERED BARRIER SEGMENT

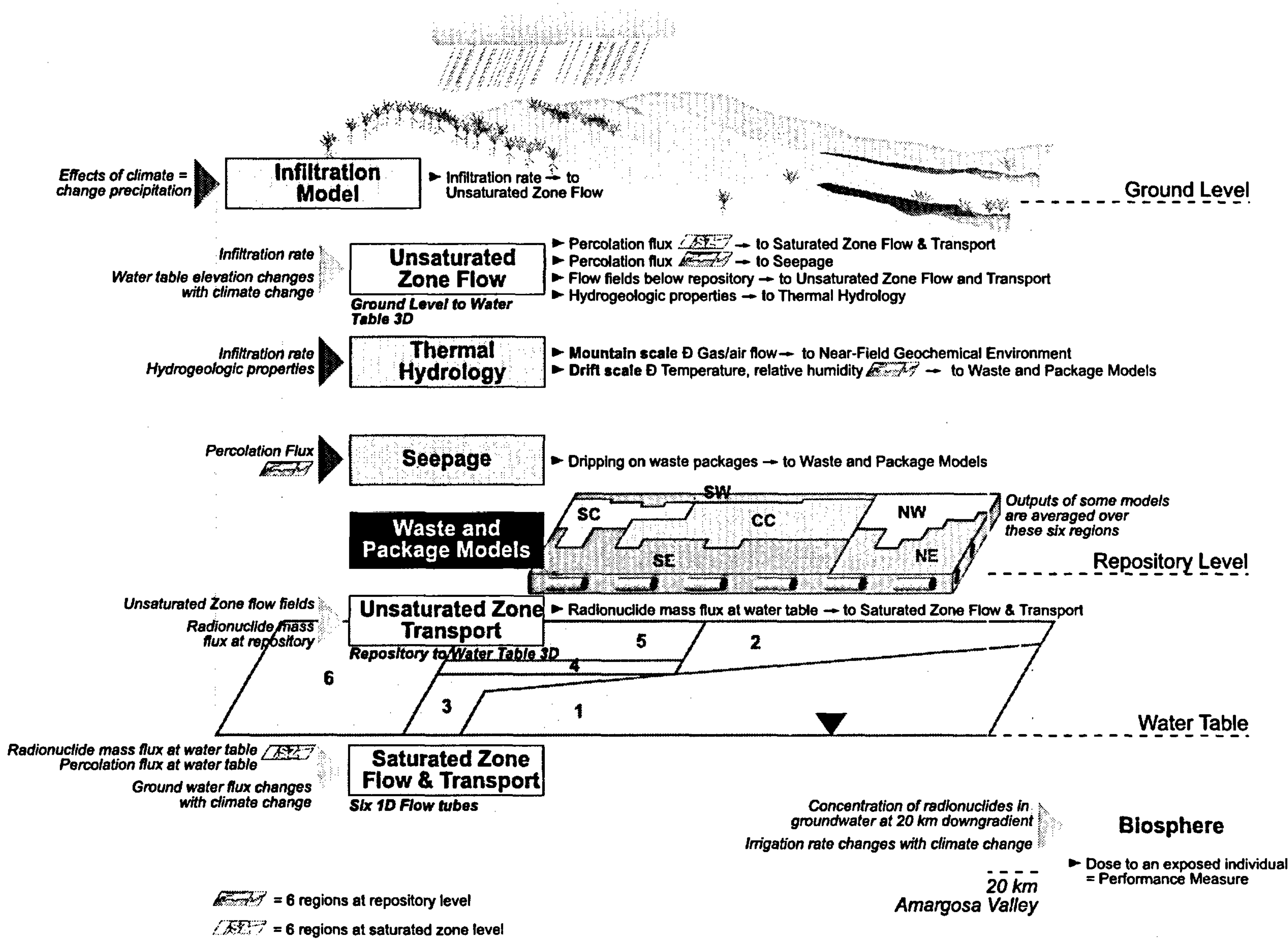
Key Features of Reference Design for Viability Assessment: Waste Package

- 21-PWR or 44-BWR CSNF
- 5-HLW canisters co-disposed with DOE SNF
- 10cm mild steel outer barrier
- 2cm C-22 inner barrier



21-PWR UCF
WASTE PACKAGE ASSEMBLY

Information Flow for TSPA-VA



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Information Flow for TSPA-VA

Waste and Package Models

Inputs	Model	Outputs	Destination
Gas flux *Air mass fraction* *Percolation flux* *Drip/No drip* *Dripping flux on packages*	**Near-Field Geochemical Environment**	Chemical conditions on or in waste package	→ to Waste Package Degradation → to Waste Form Mobilization → to Radionuclide Mobilization
Temperature *Relative Humidity* *Drip/No drip* *Chemical Conditions*	**Waste Package Degradation**	Waste package failure Information over time - Number of packages - Size of package breaches	→ to Waste Form Degradation → to Engineered Barrier System Transport
Chemical conditions *Temperature*	**Cladding**	Surface of waste form exposed	
Number of packages failed over time *Geochemical conditions* *Temperature*	**Waste Form Degradation**	Amount of radionuclides available for mobilization over time	→ to Radionuclide Mobilization
Amount of radionuclides available for mobilization over time *Geochemical conditions* *Temperature* *Dripping flux on waste packages*	**Radionuclide Mobilization**	Source term Amount of radionuclides mobilized (available for transport) over time	→ to Engineered Barrier System Transport
Size of package breaches *Liquid saturation in invert (from TH)* *Dripping flux on waste packages*	**Engineered Barrier System Transport**	Radionuclide mass flux at repository	→ to Unsaturated Zone Transport

= 6 regions at repository level

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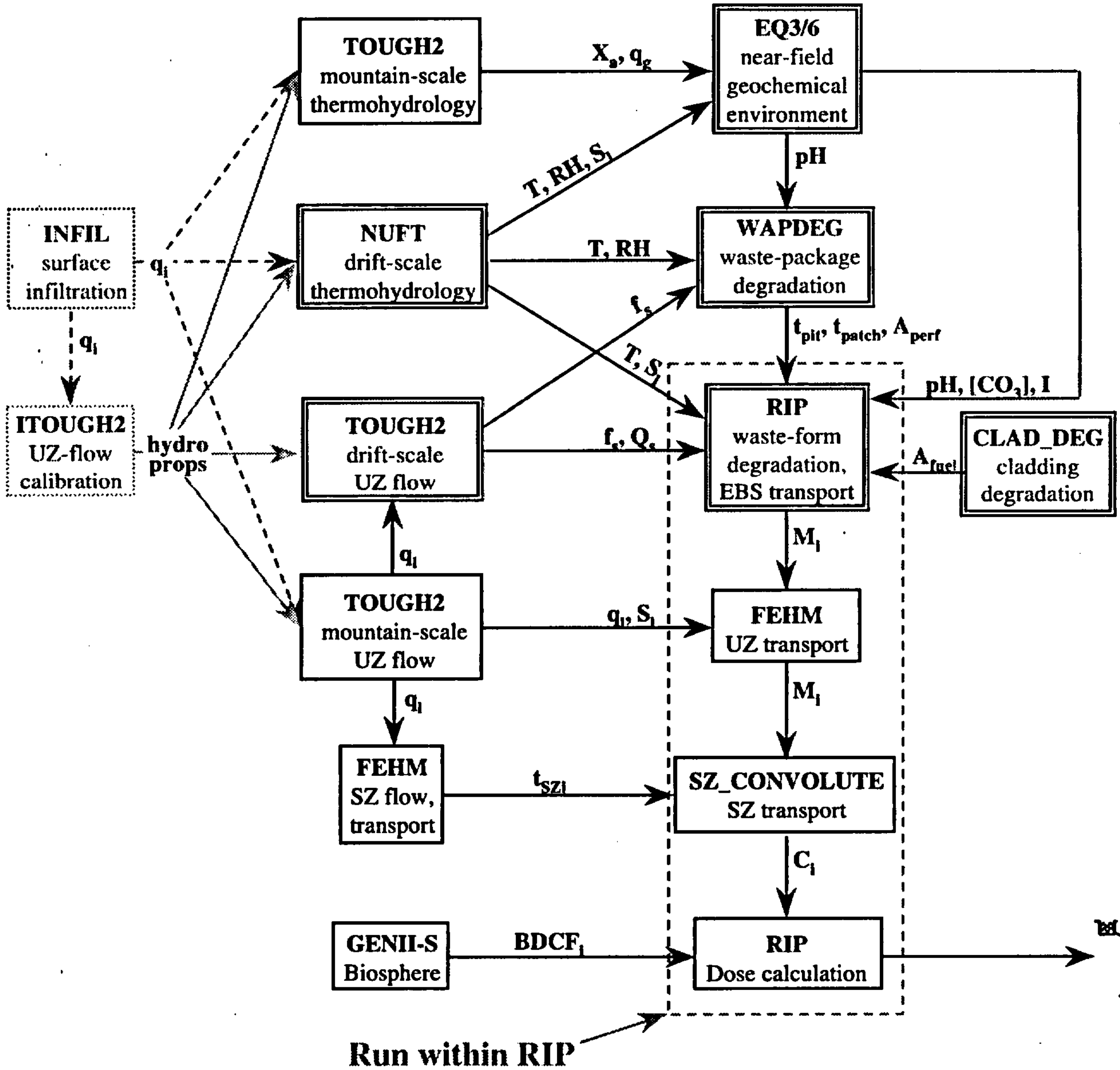
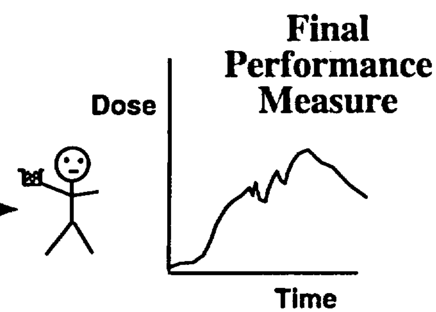
TSPA-VA Code Configuration

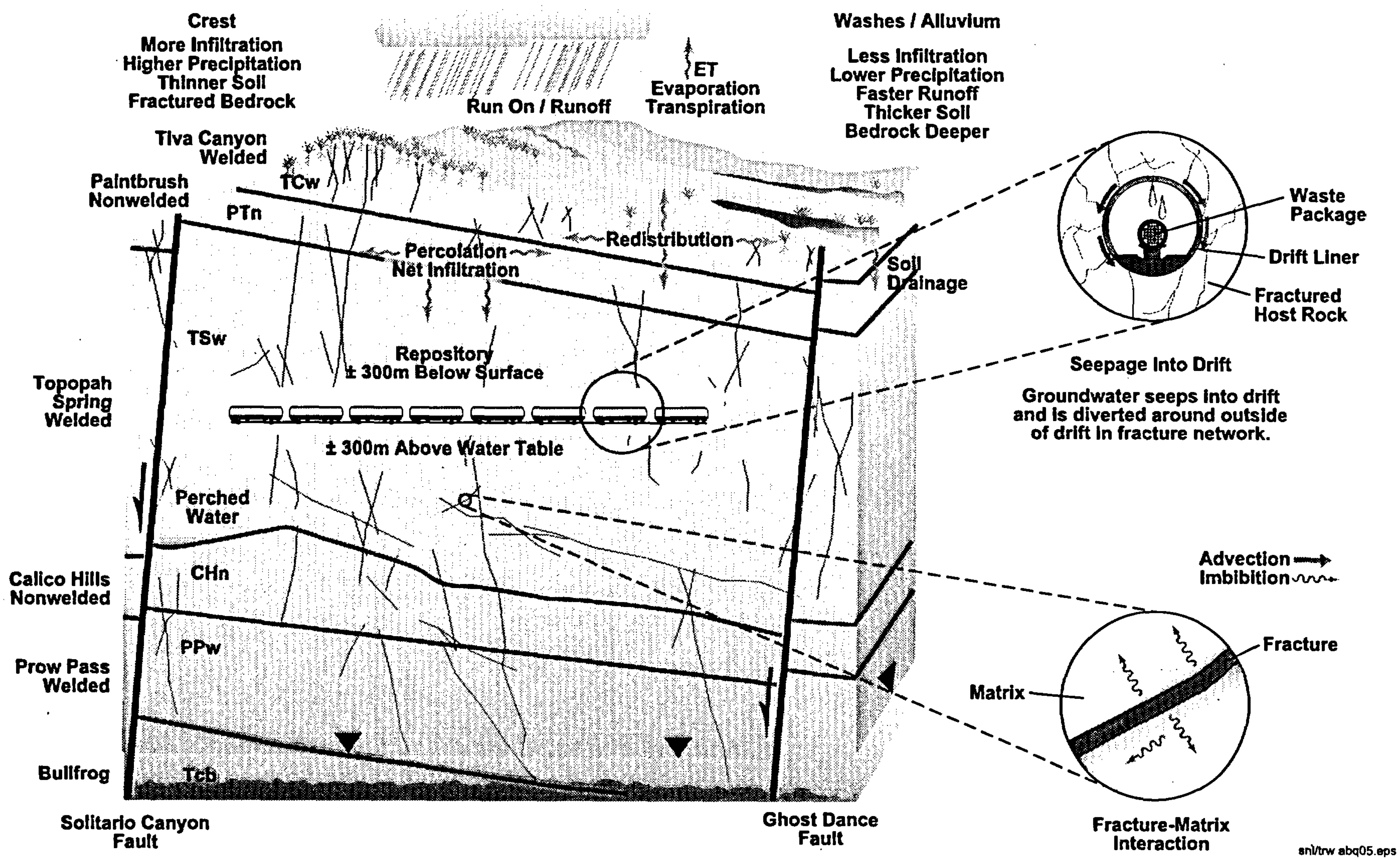


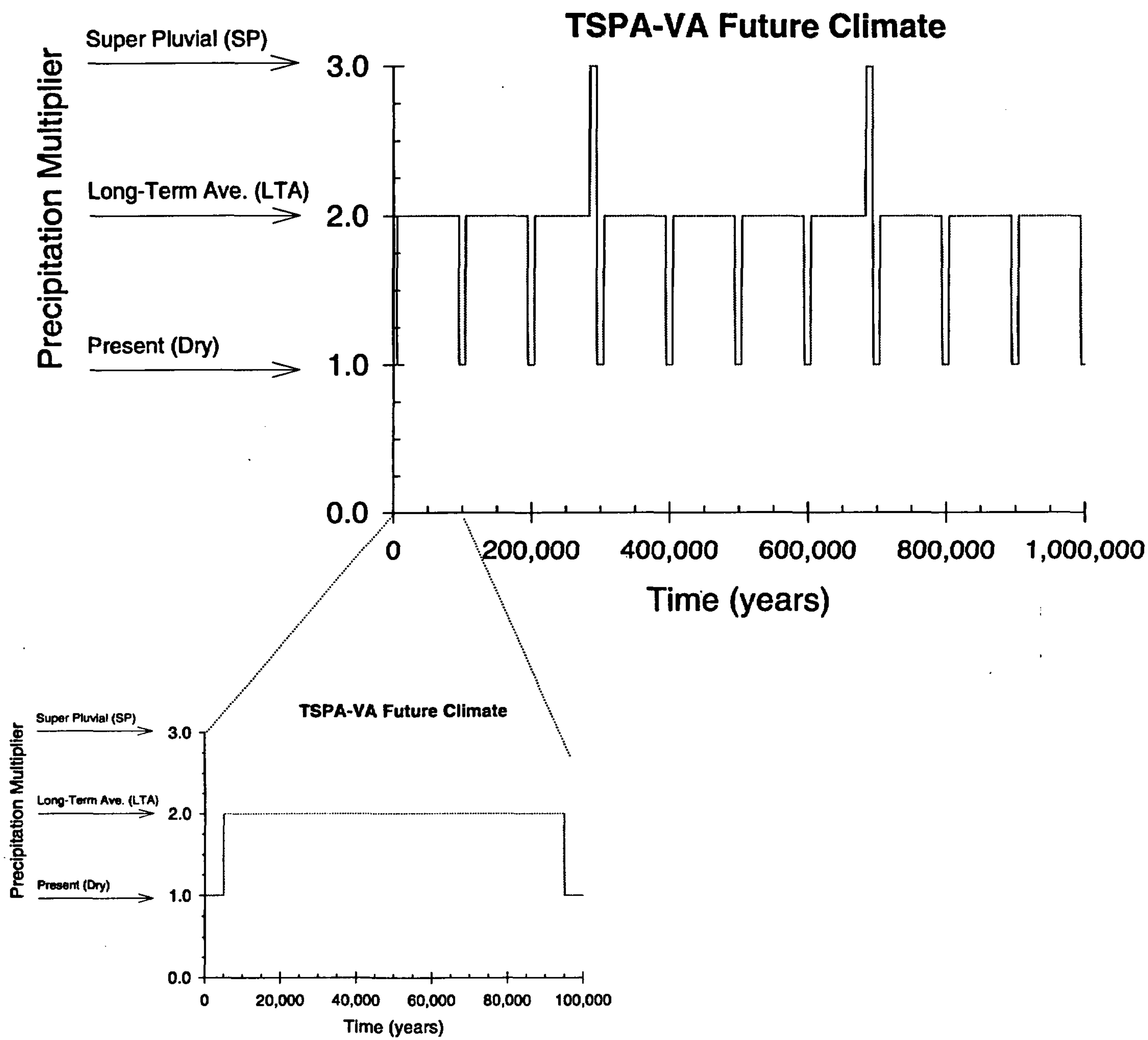
OUTPUT Parameters

T	Temperature
RH	Relative humidity
S_l	Liquid saturation
X_a	Air mass fraction
q_g	Gas flux
q_l	Liquid flux
q_i	Infiltration flux
f_s	Fraction of WPs with seeps
Q_s	Seep flow rate
pH	pH
$[CO_3]$	Carbonate concentration
I	Ionic strength
t_{pit}	Initial-pit-penetration time
t_{patch}	Initial-patch-penetration time
A_{perf}	Perforated container area
A_{fuel}	Exposed fuel area
M_i	Radionuclide mass flux
C_i	Radionuclide concentration
t_{SZi}	SZ transport time
$BDCF_i$	Biosphere dose conversion factor



Conceptual Models of Hydrologic Processes





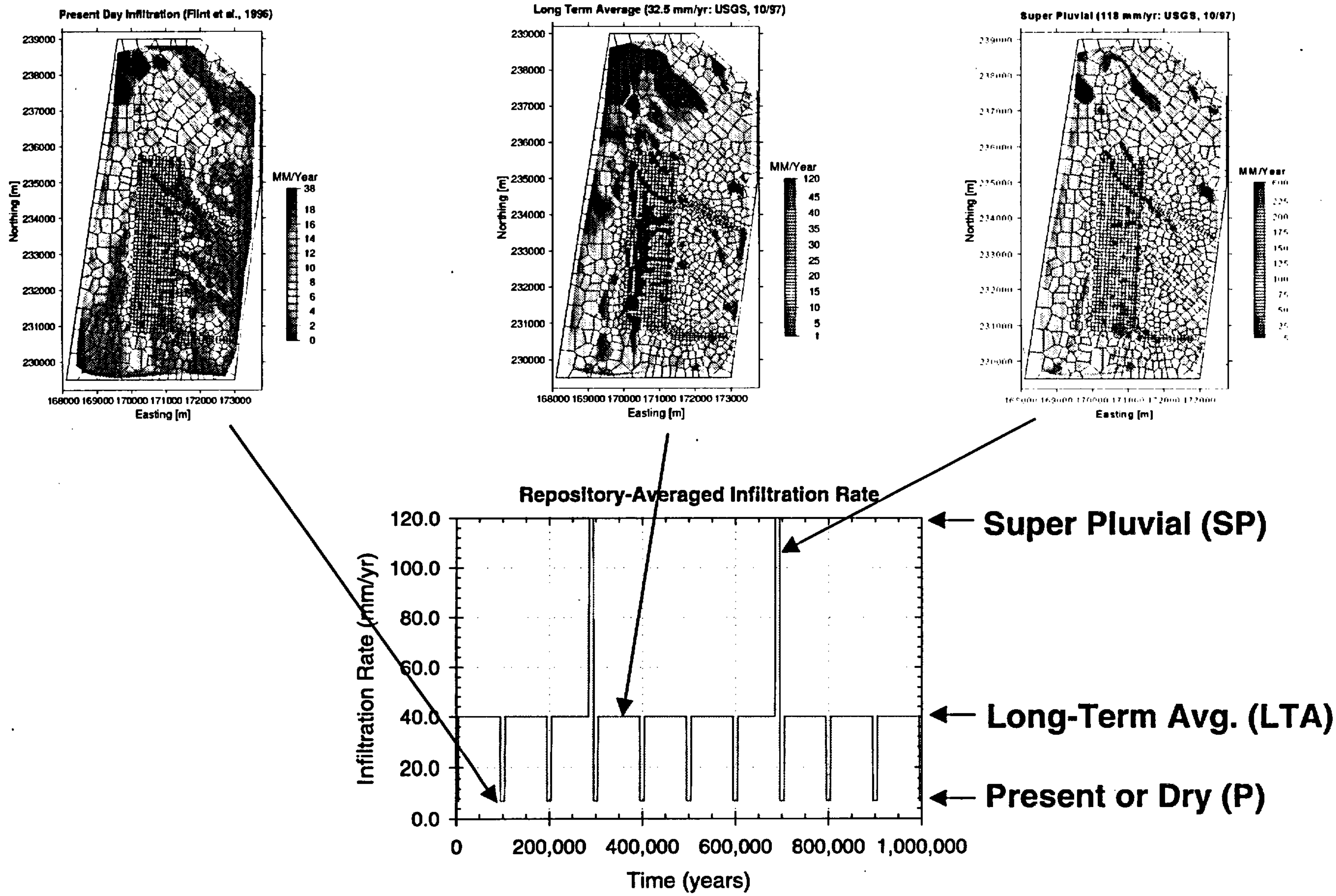
TSPA-VA Future Climate
Precipitation Multiplier
Super Pluvial (SP)
Long-Term Ave. (LTA)
Present (Dry)
3.0
2.0
1.0
0.0
0
200,000
400,000
600,000
800,000
1,000,000
Time (years)
TSPA-VA Future Climate
Precipitation Multiplier
Super Pluvial (SP)
Long-Term Ave. (LTA)
Present (Dry)
3.0
2.0
1.0
0.0
0
20,000
40,000
60,000
80,000
100,000
Time (years)

TSPA Base Case Climate History (Precipitation)

- Use 3 climate states
  - Present (dry)
  - Long-Term Average
  - Super Pluvial
- Assume instantaneous change between climate states
- Durations
  - Present (5,000 yrs.)
  - Long-Term Average (90,000 yrs.)
  - Super Pluvial (10,000 yrs.)
- Timing
  - Present (~ every 100,000 yrs.)
  - Long-Term Average (~ 80% of time)
  - Super Pluvial (~ every 300,000 yrs.)
- Magnitude
  - Long-Term Average (2x Present Precipitation)
  - Super Pluvial (3x Present Precipitation)

TSPA-VA Base Case Infiltration History

<P> ~ 7 mm/yr   <LTA> ~ 40 mm/yr   <SP> ~ 120 mm/yr



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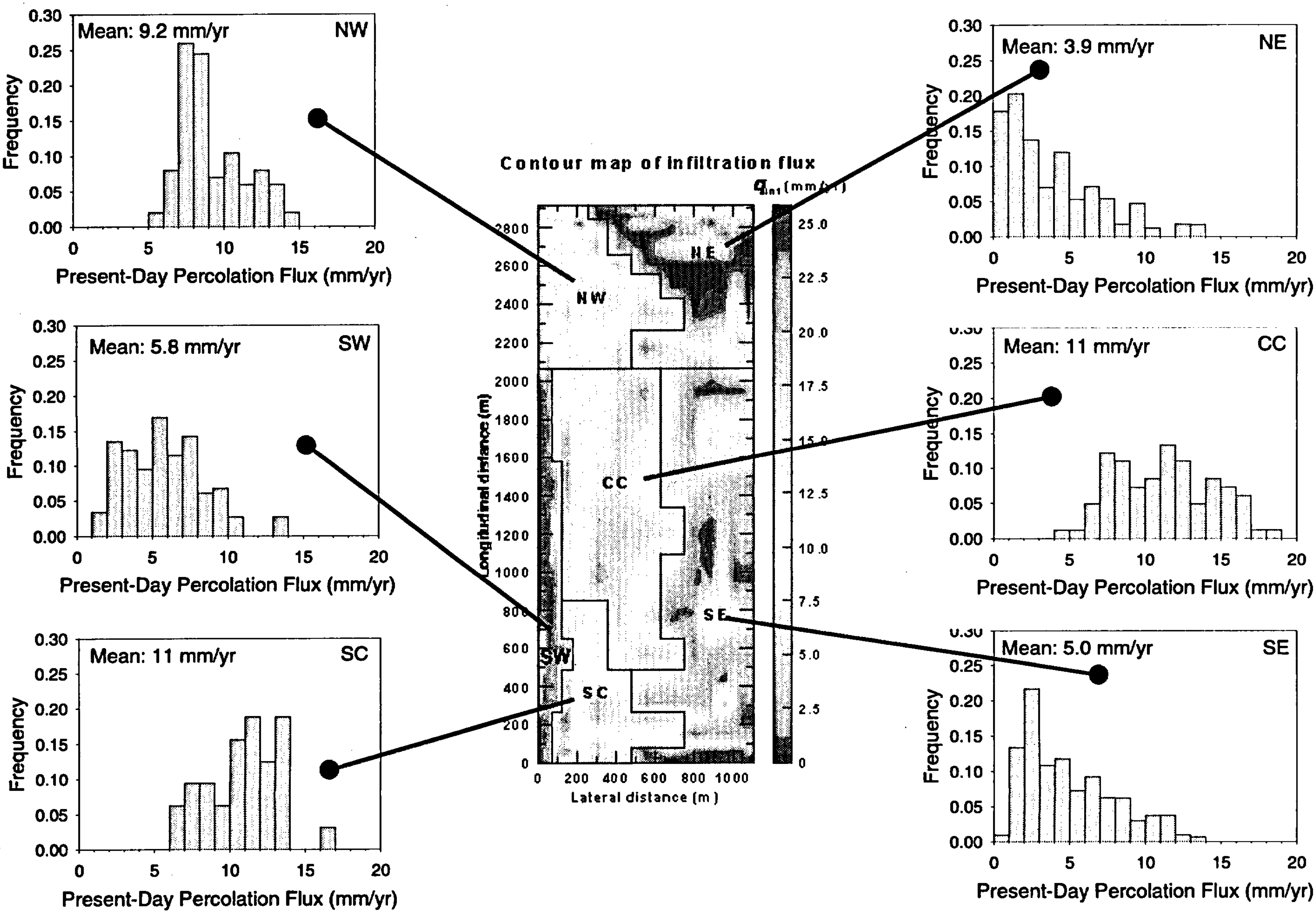
TSPA-VA Base Case Infiltration History

- Present infiltration model (Flint and Hevesi) calibrated to shallow neutron holes
- Infiltration model used to extrapolate the effects of precipitation changes
- Infiltration changes non-linearly with precipitation due to duration, intensity and timing of precipitation
- Three discrete infiltration rates used as input to UZ Flow Model

TSPA-VA Base Case Unsaturated Zone Flow: Percolation Flux



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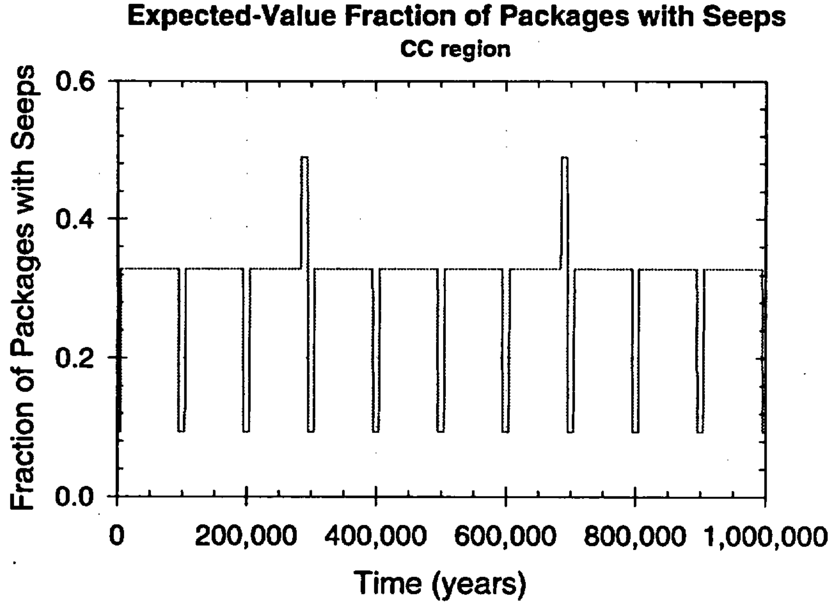
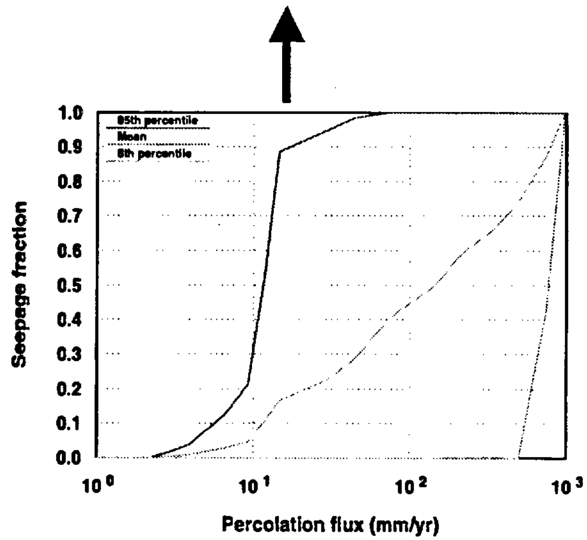
TSPA-VA Base Case Unsaturated Zone Flow Model

- UZ Flow Model calibrated with matric potential, temperature, chloride, Cl-36, perched zones, pneumatics
- Percolation flux varies spatially, but is subdued reflection of infiltration
- Percolation at repository discretized into six regions, ranging from
  - 4 to 11 mm/yr (present-day climate);
  - 31 to 55 mm/yr (long-term average);
  - 81 to 140 mm/yr (super pluvial)

TSPA-VA Base Case Seepage: Fraction of Waste Package with Seeps

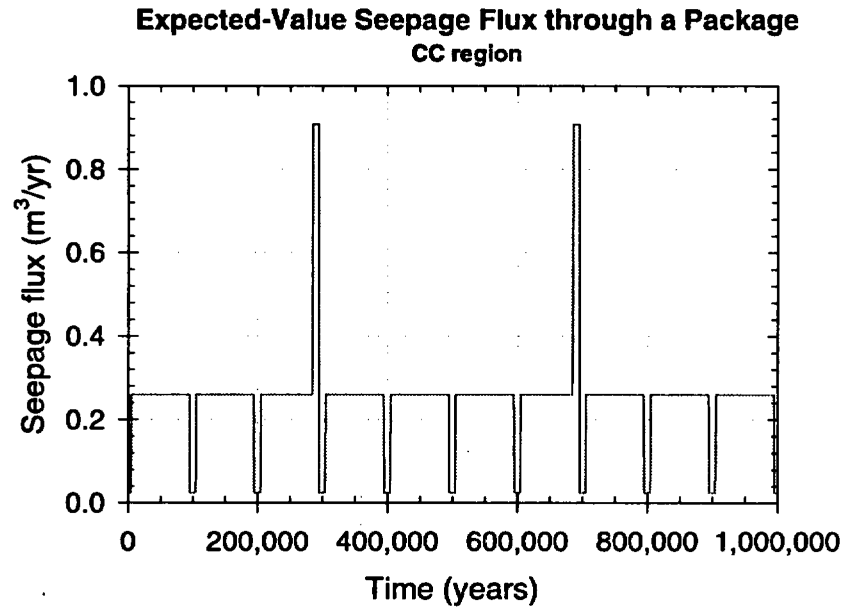
- Seepage fraction defines the probability of a seep intersecting a waste package
- Seepage model considers heterogeneous fracture network
- Conservatively assume all seeps above spring line can intersect waste package
- Long-Term Average mean fraction of packages with seeps is ~0.3 (varies between six discrete regions)
- Uncertainty in seepage fraction due to uncertainty in fracture permeability and capillarity

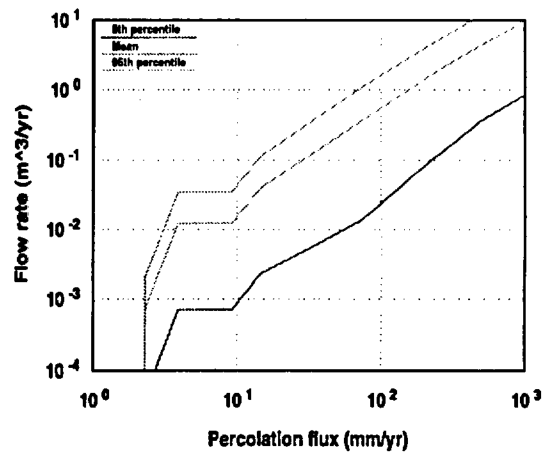




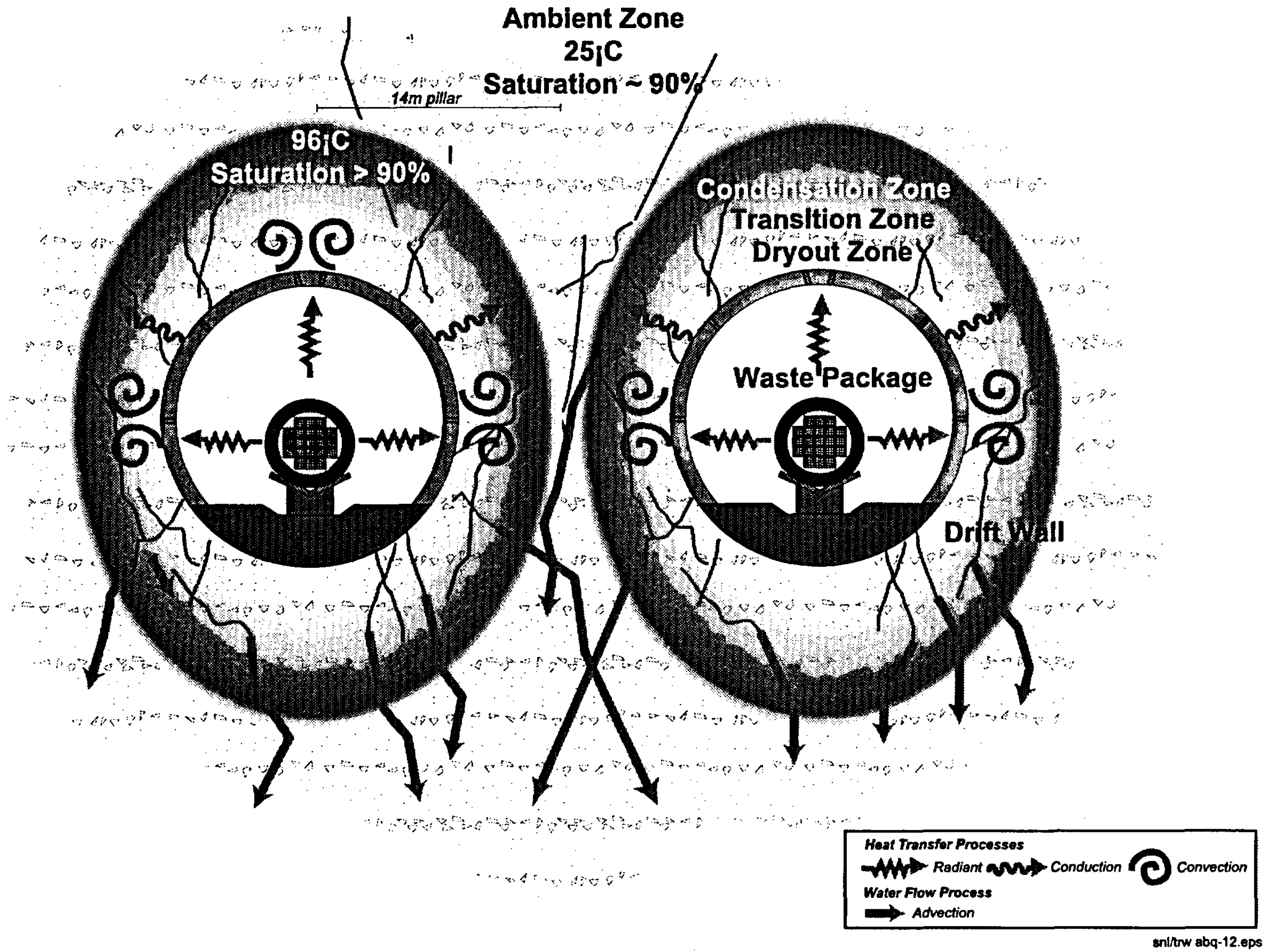
TSPA-VA Base Case Seepage: Seepage Flux

- Seepage model fluxes compare with ESF niche tests (about 1,000 - 10,000 x ambient flux)
- Seepage flux determined by adding fluxes from each individual modeled seep which intersects a waste package
- Long-Term Average mean seepage flux is ~ 0.2 m^3/yr (varies between six discrete regions)
- Given ~ 30% of packages see seeps (LTA) and average seepage flux is ~0.2 m3/yr; ~ 1,000 m3/yr seeps into drifts, which is ~ 1/200 or 0.5% of total percolation flux across repository footprint

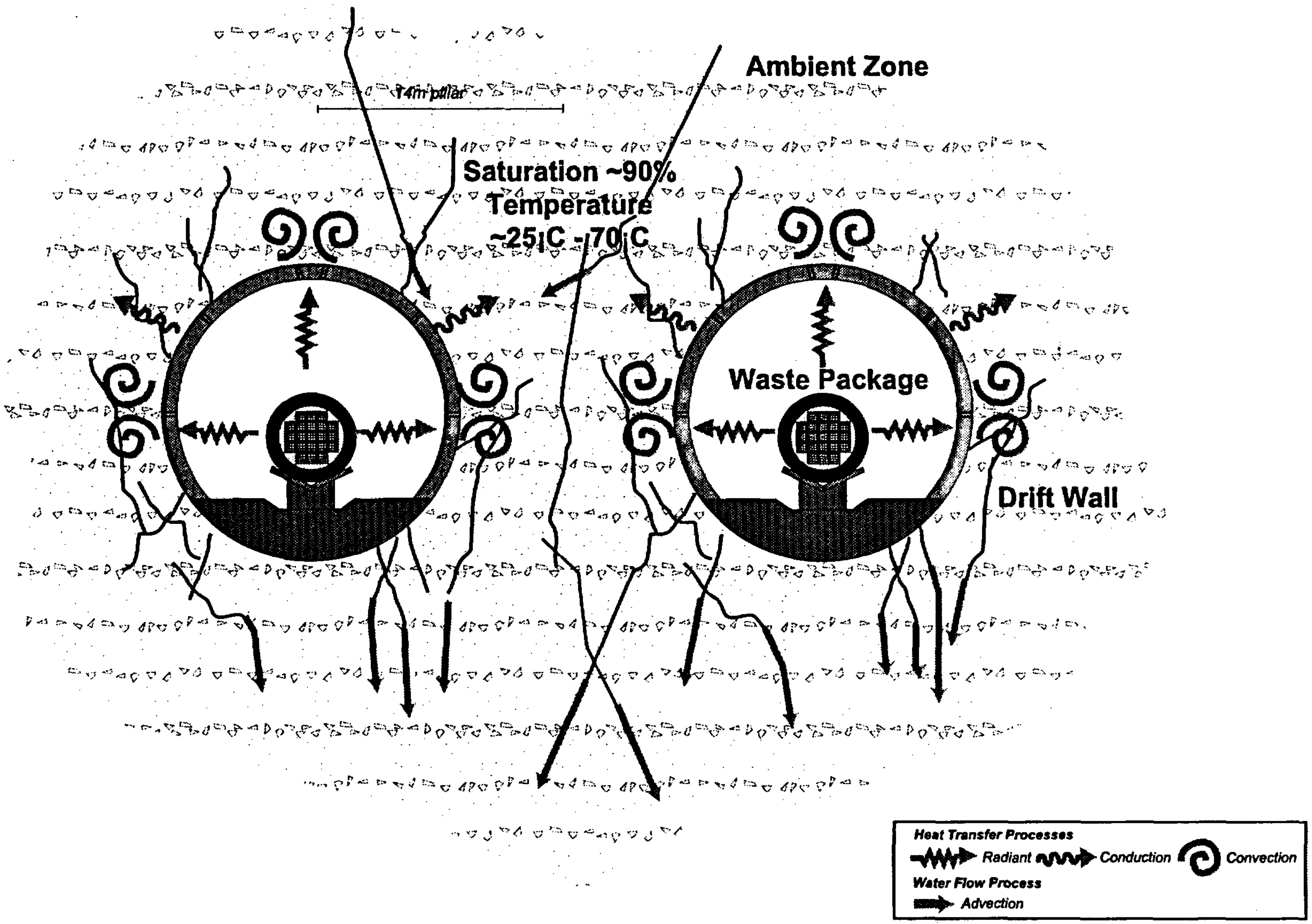




Thermal Hydrology in TSPA-VA



Thermal Hydrology in TSPA-VA



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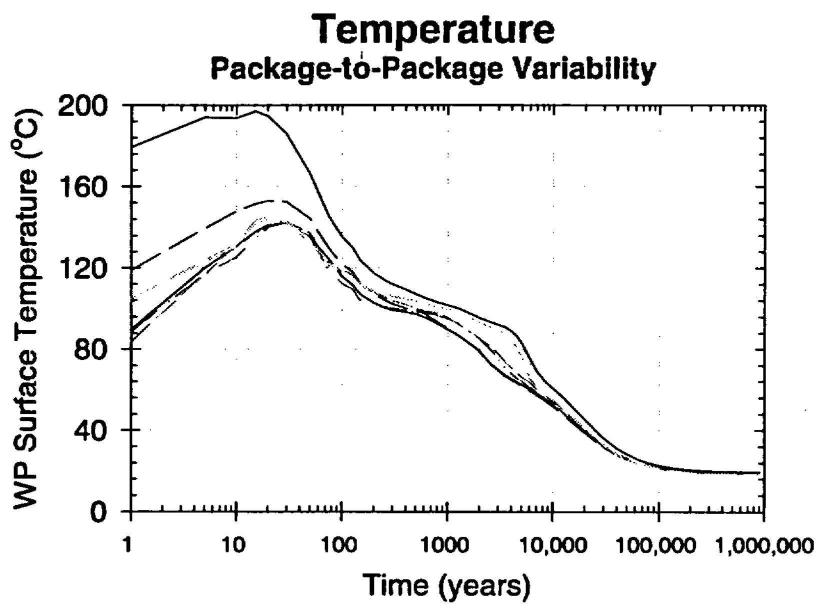
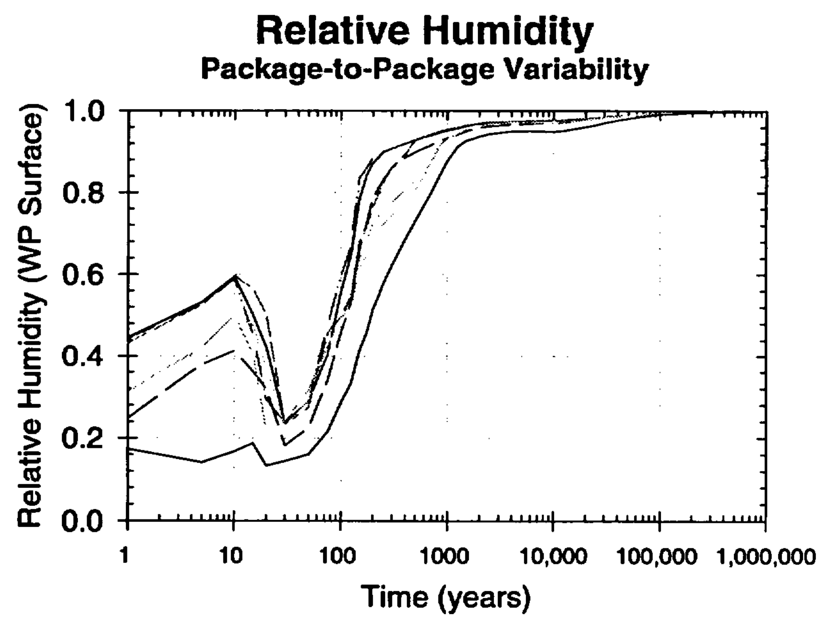
TSPA-VA Base Case Thermal Hydrology

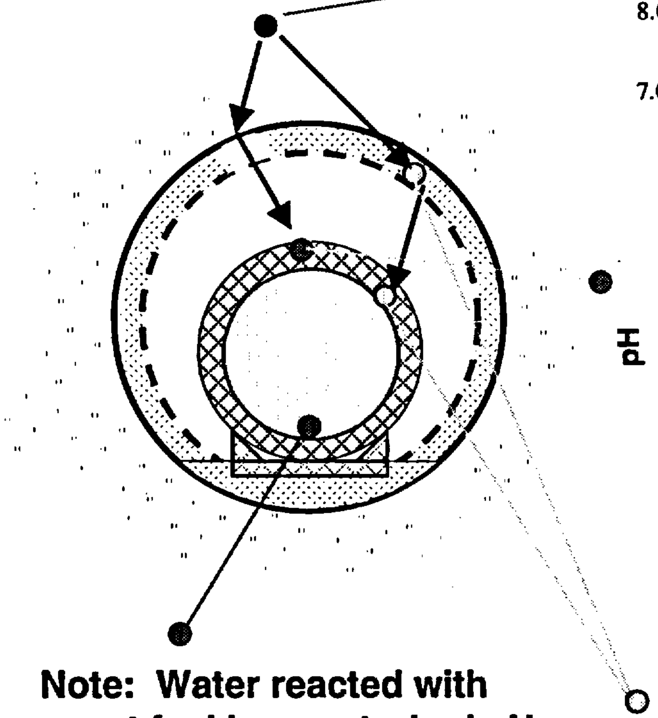
- Thermal hydrology model used to predict single heater test and drift-scale test results
- Principal results used are temperature and relative humidity on waste package surface and saturation in invert
- Redistribution of moisture (modified fluxes) analogous to assuming Long-Term Average percolation fluxes occur at 2,000 - 3,000 years after emplacement
- Variability in T/RH response in six regions and for different waste packages – variability is minimal after ~ 1,000 years

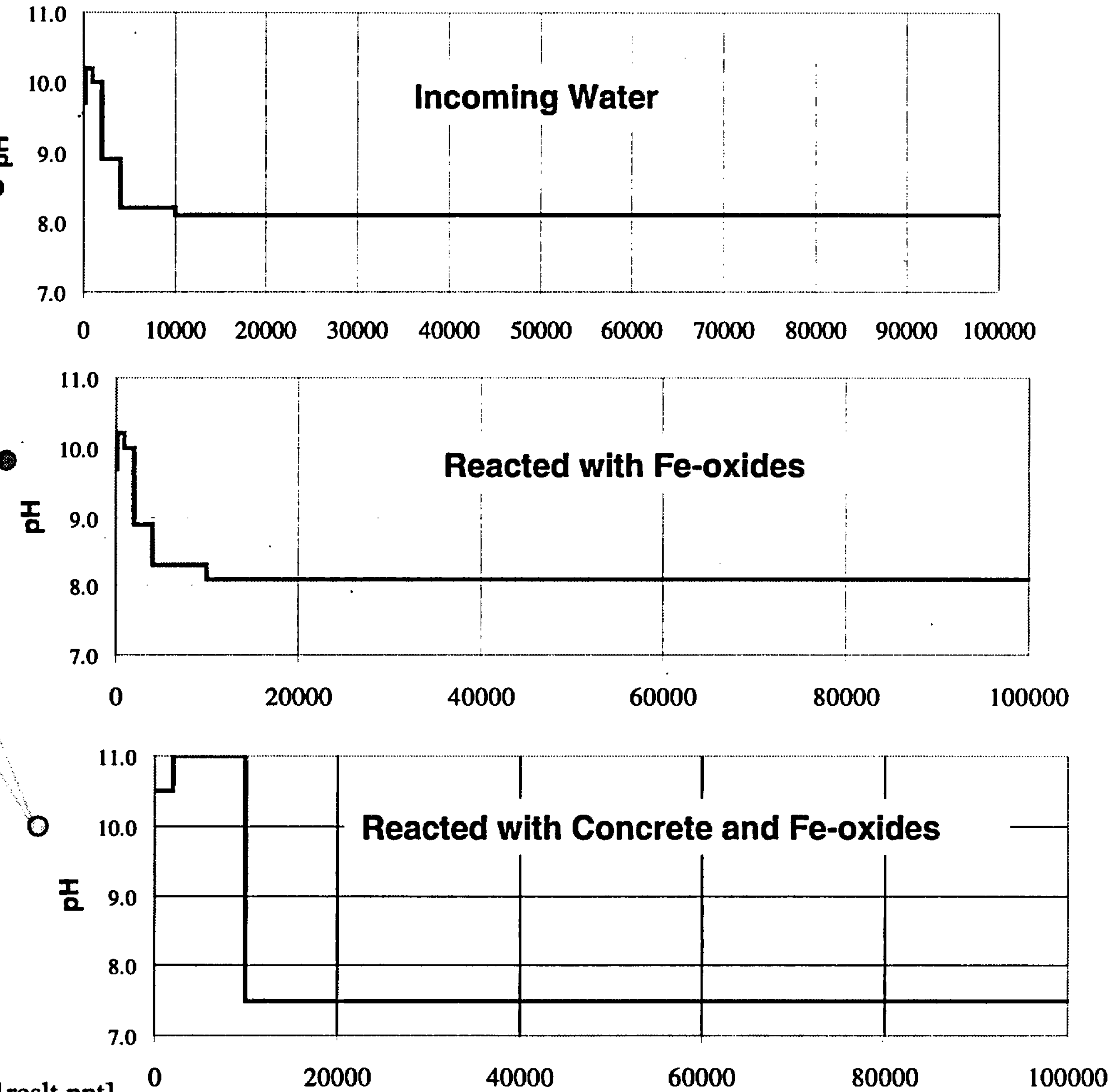




TSPA-VA Base-Case Near-Field Geochemical Environment

[Schematic, not design drawing]





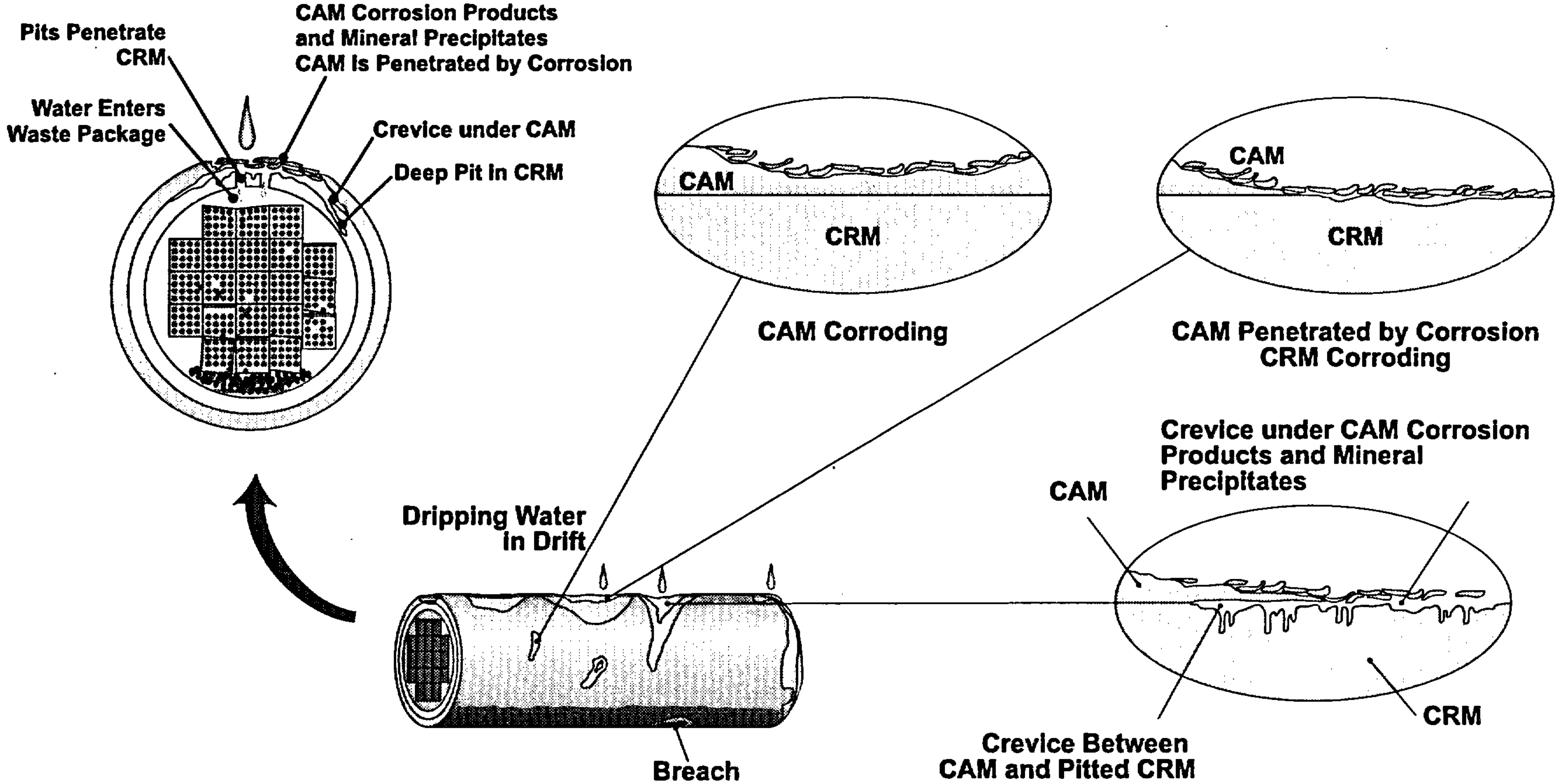
Note: Water reacted with spent fuel has perturbed pH only during active alteration of original UO_2. This is approximately 500-1000 years.

[Revised 20-Apr-98, NFGErev01reslt.ppt]

TSPA-VA Base Case Near Field Geochemical Environment

- Geochemistry in drift controlled by air mass fraction determined from mountain-scale thermal hydrology
- Discrete time windows used to evaluate batch chemical equilibrium
- Chemistry altered by presence of
  - Concrete liner
  - Steel
  - Glass or spent fuel waste forms
- Key geochemical parameters are
  - pH (WP degradation, WF degradation, solubility
  - CO_3 (WF degradation, solubility)
  - I (colloid stability)

Waste Package Degradation



CAM = Corrosion Allowance Material Outer Barrier

CRM = Corrosion Resistant Material Inner Barrier

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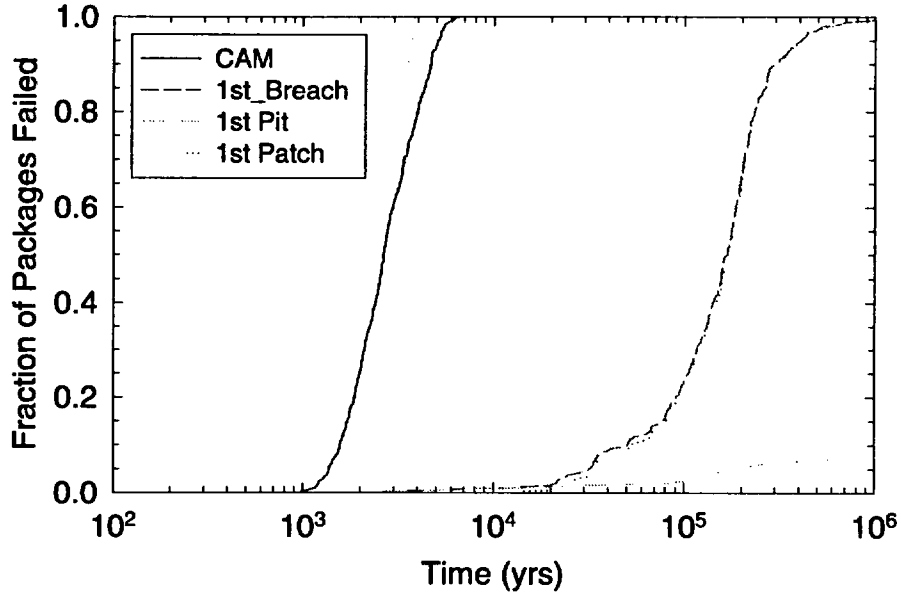
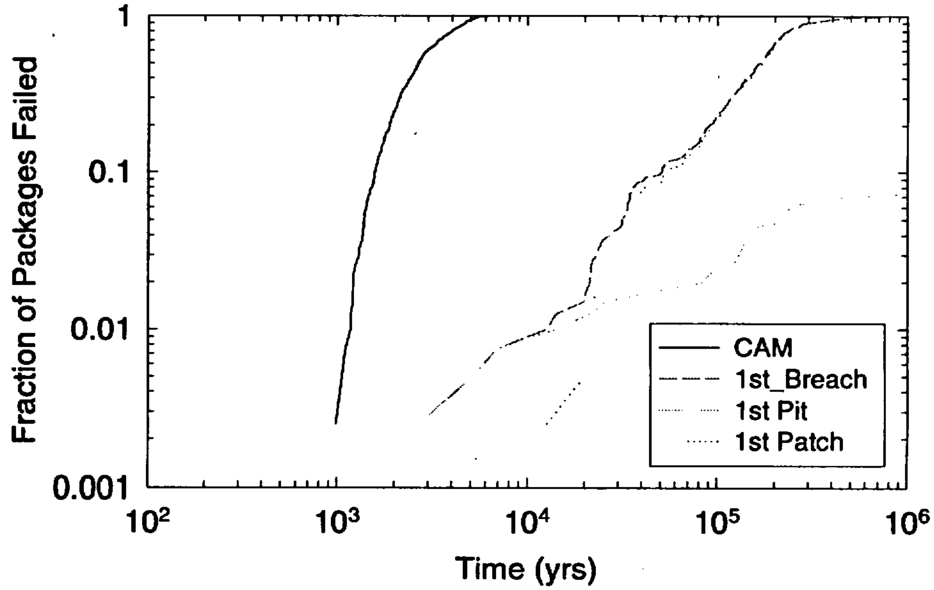
TSPA-VA Base Case Waste Package Degradation: Initial "Failure"

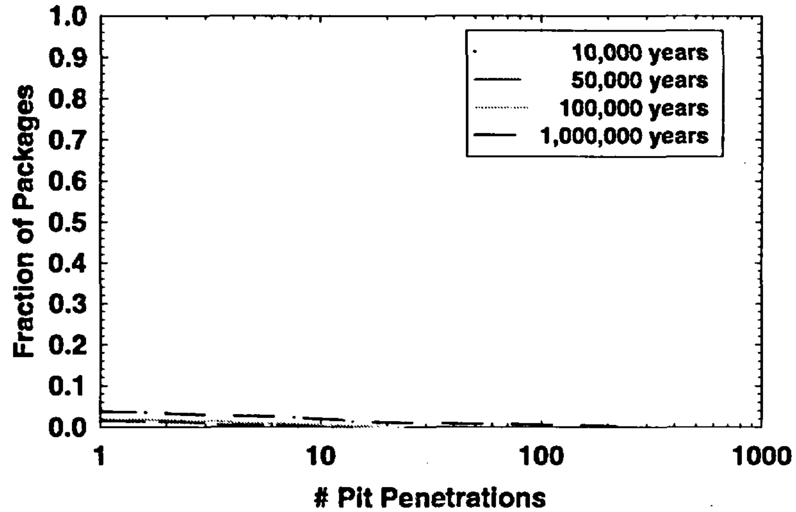
- "Failure" defined by initial pits (mm^2) or patch (100's cm^2) opening through corrosion resistant material
- Primary degradation method is corrosion
- Possible early failures considered - one waste package at 1,000 years in base case
- Rate of "failure" of waste packages with seeps is ~2% / 10,000 years
- Earliest corrosion "failures" are by pits at ~ 3,000 years and by patches at ~ 10,000 years
- Waste packages without seeps do not "fail" until several 100,000 years

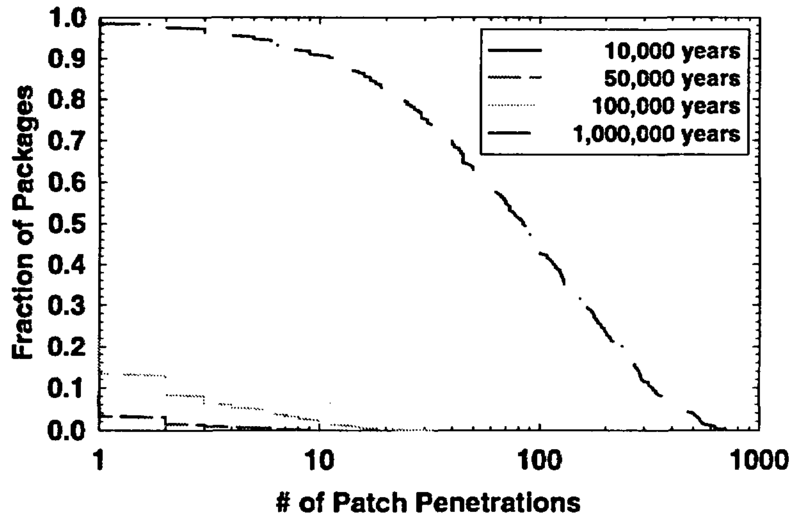




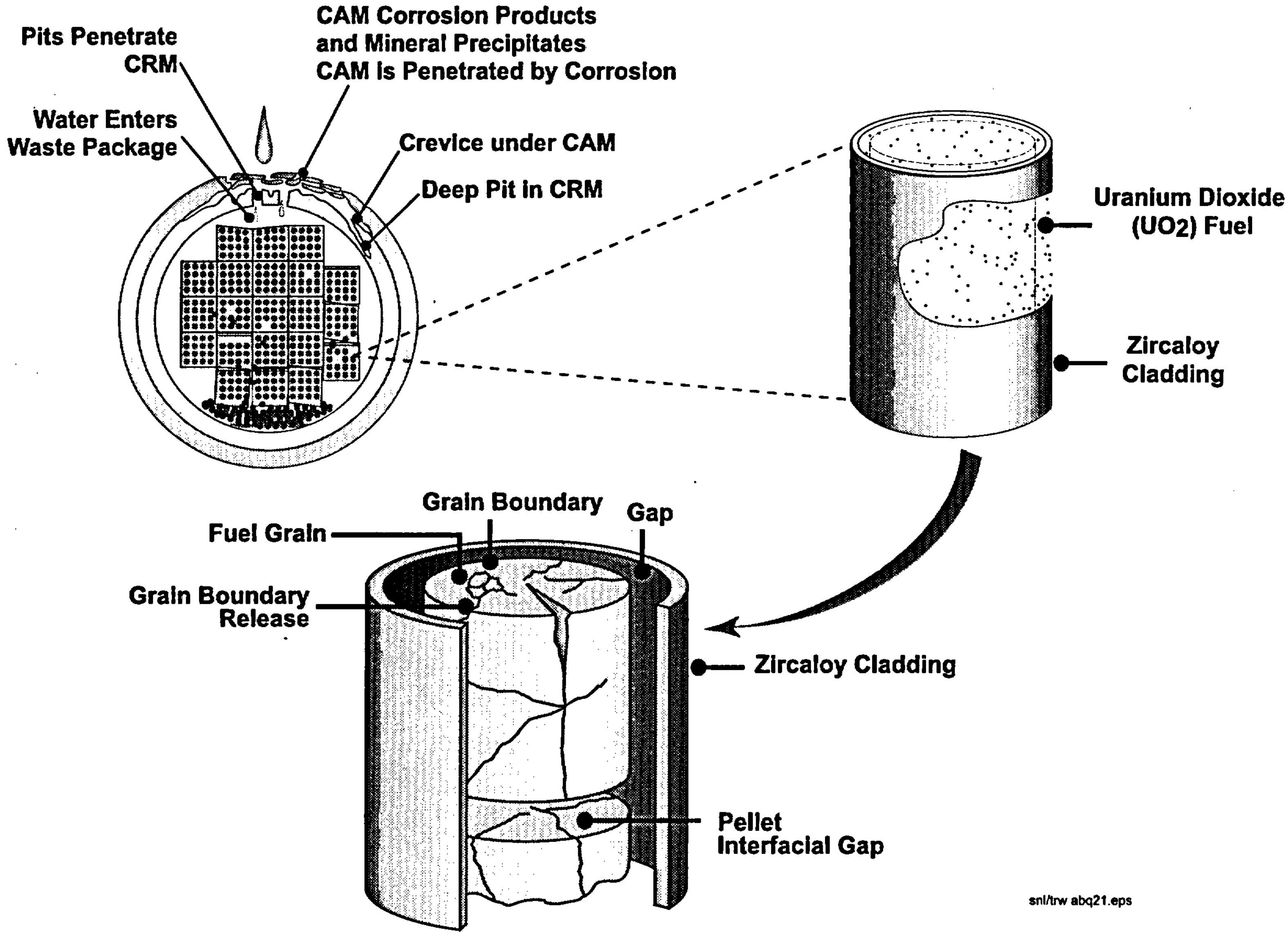
TSPA-VA Base Case Waste Package Degradation: Surface Area "Failed"

- Percent of waste package surface exposed used to define percent of seepage flux which can enter waste package
- Regardless of where the first breach occurs, seeps are assumed to intersect the exposed openings
- Seeps are allowed to infiltrate package even if openings are pit size and filled with corrosion product
- Due to larger area, patches are more significant for EBS releases of solubility – limited radionuclides



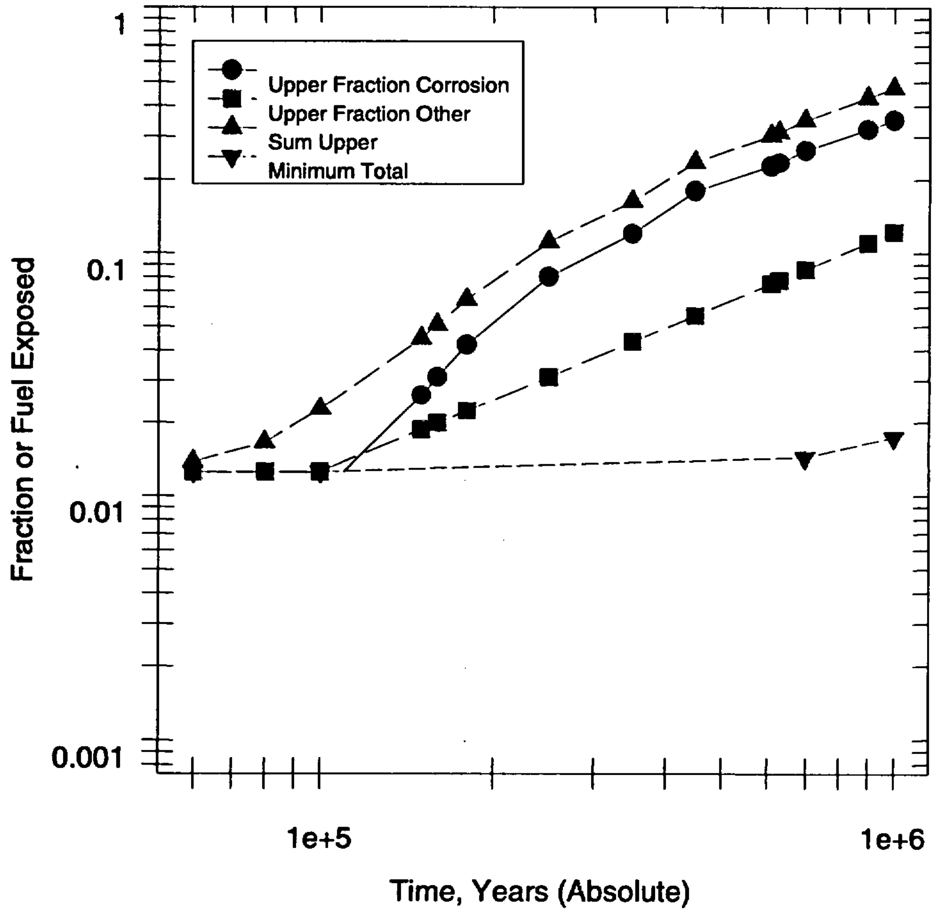


Waste Form Degradation



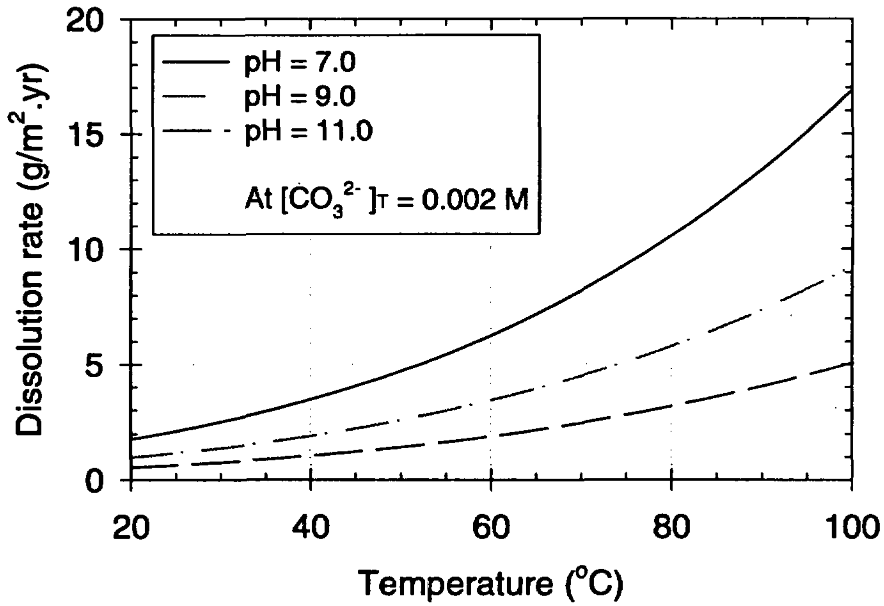
TSPA-VA Base Case Cladding Degradation

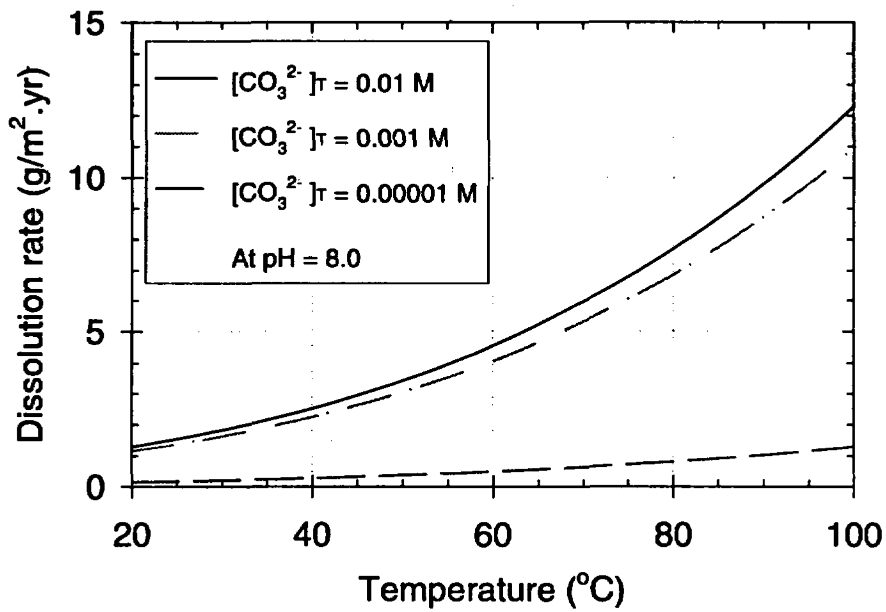
- Cladding degradation defines fraction of fuel exposed which could potentially be contacted by water
- Early degradation defined by seep, premature failures and stainless steel fraction (<2%)
- Late degradation defined by corrosion and mechanical failure (mean ~10% @ 1,000,000 years)
- Corrosion determined by scaling Zircaloy corrosion to C-22 corrosion under similar conditions (~100 x more corrosion resistant)
- As cladding degrades with time, increased fuel surface area is potentially exposed to water



TSPA-VA Base Case Waste Form Degradation

- Each waste type (CSNF, HLW, DOE, SNF, Navy, Pu) has a different degradation rate
- Degradation rates based on laboratory observations
- For CSNF specific surface area of ~10^{-4} m^2/g, degradation is ~1,000 years
- Assume that 100% of exposed surface is contactec by water





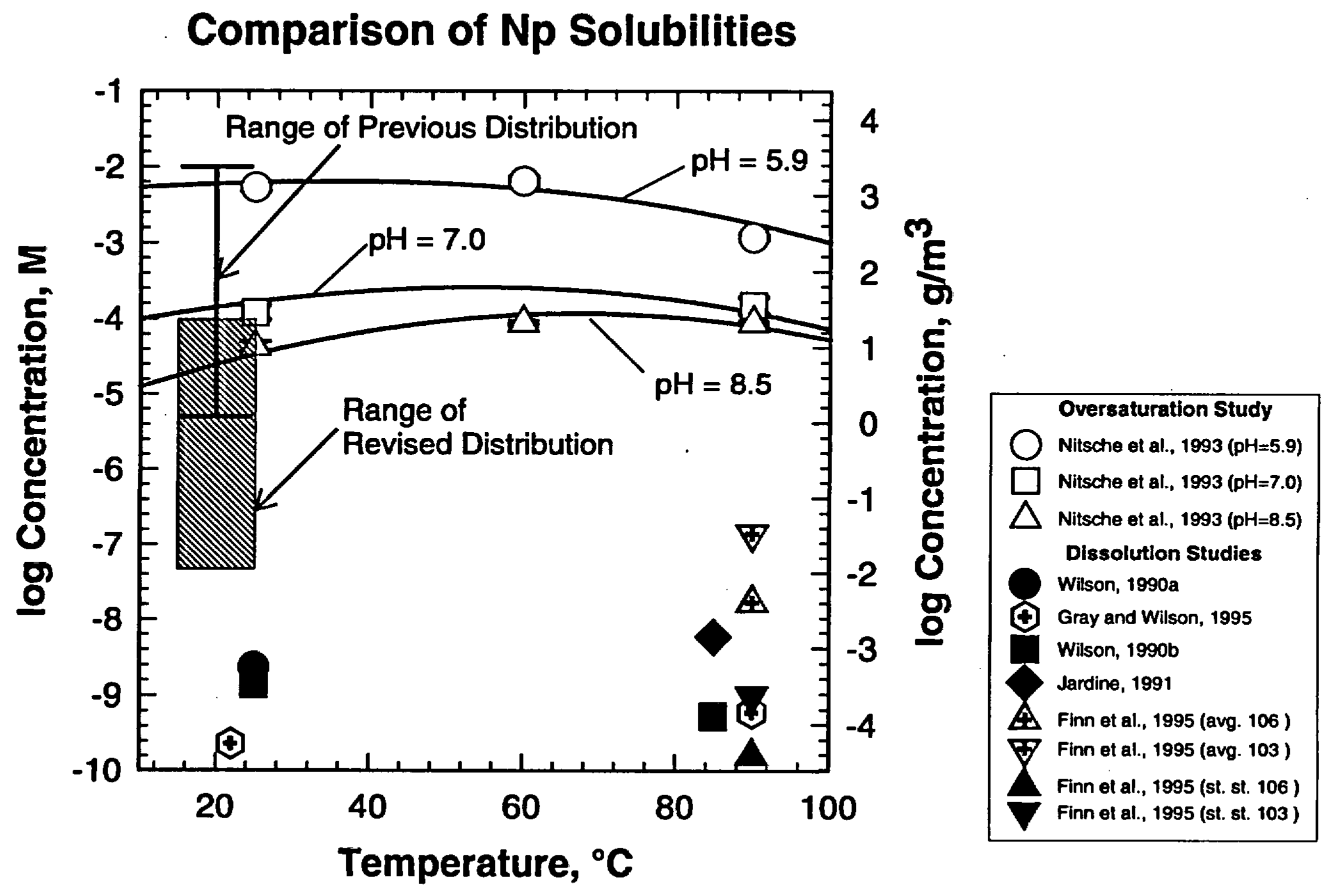
TSPA-VA Base Case Radionuclide Mobilization: Colloids

- Consider natural (clay, iron oxide) and waste form (glass, spent fuel) colloids
- Colloid stability is a function of ionic strength
- Consider Pu Colloids
- Reversible colloids consider sorption / desorption of Pu onto / off of colloids
- Irreversible colloid fraction derived from comparison with observations near Benham shot

TSPA-VA Base Case Radionuclide Mobilization: Solubility

- Tc, I, C have very high solubilities - their release is limited by the rate of release from the waste form
- Np solubility examined in far from equilibrium conditions (either oversaturation in J-13) or in presence of spent fuel
- Np solubility range is 100 x lower than used in TSPA-95; consistent with equilibrium geochemistry model
- U, Pa and Pu are also solubility limited

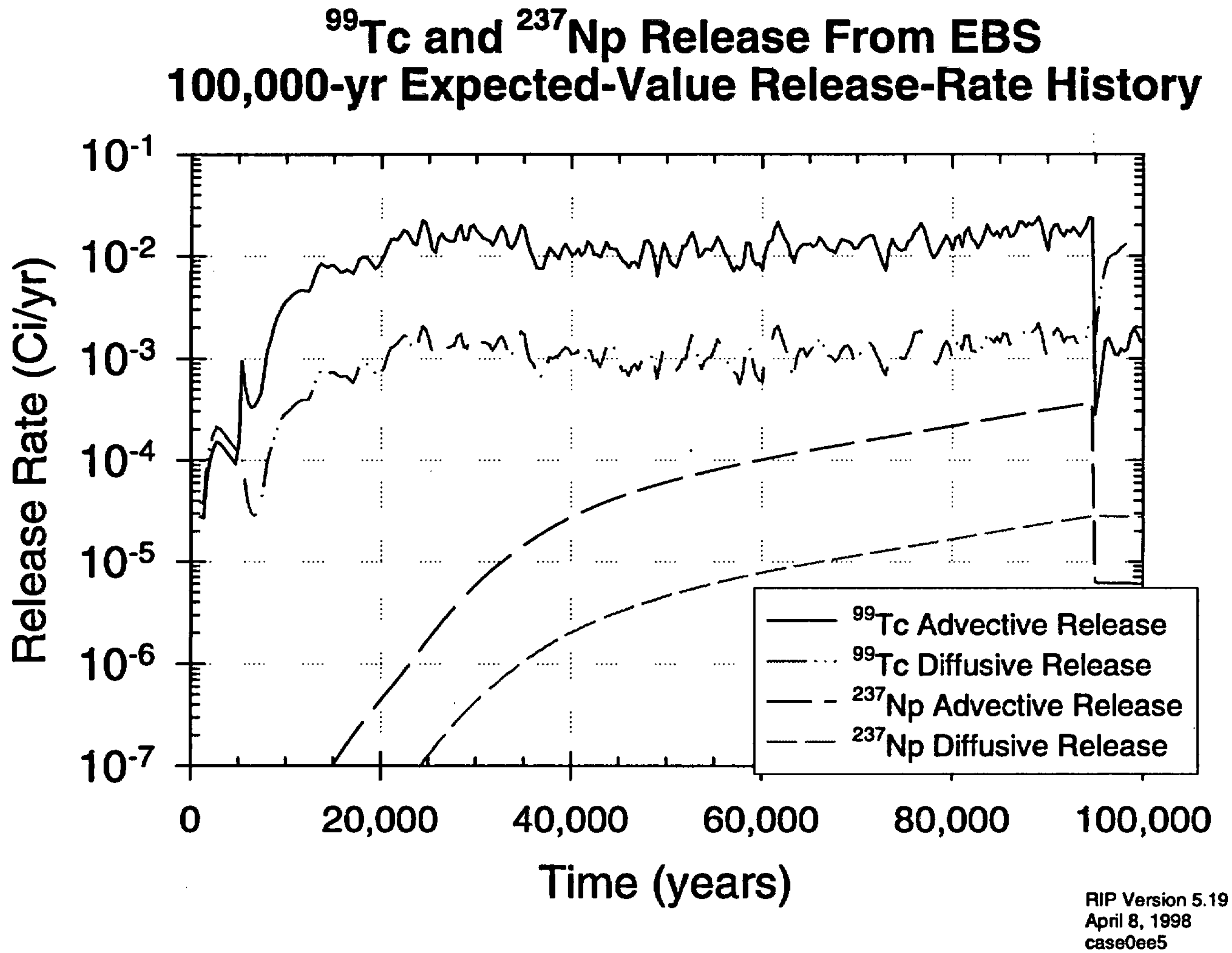
TSPA-VA Base Case Radionuclide Mobilization: Solubility



TSPA-VA Base Case Engineered Barrier System Transport

- Advection out of waste package controlled by the seepage flux which enters the waste package
- Seepage flux into waste package is a function of seepage into drifts and percent of waste package surface exposed and a scaling factor (1-10) to account for uncertainty
- Diffusion through waste package is a function of percent of waste package surface exposed
- Diffusion through invert is a function of liquid saturation in invert which is high for assumed properties of degraded invert
- No retardation considered in degraded waste package or invert materials

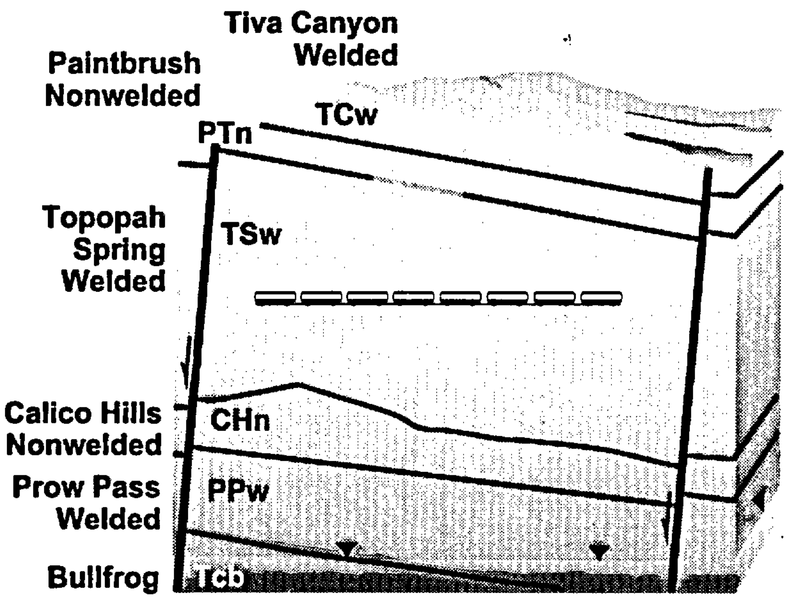
TSPA-VA Base Case Engineered Barrier System Transport: EBS Release Rates



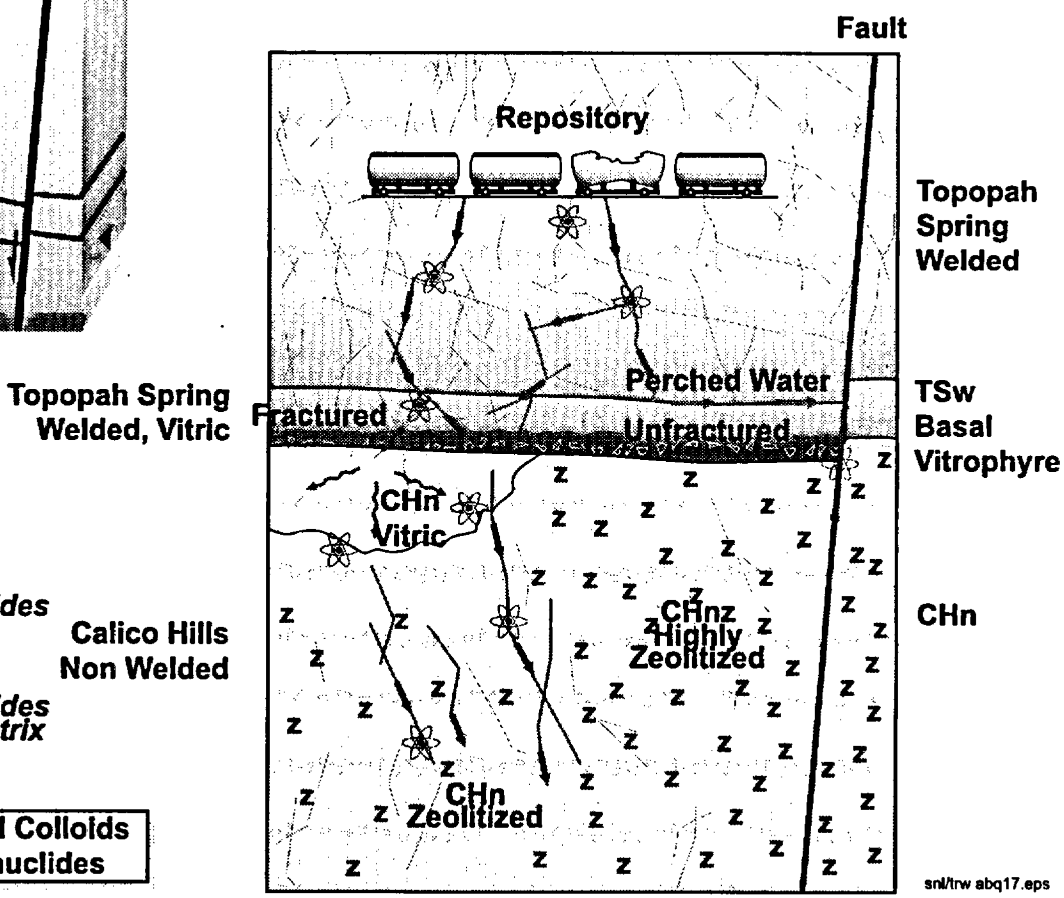
TSPA-VA Base Case Engineered Barrier System Transport: EBS Release Rates

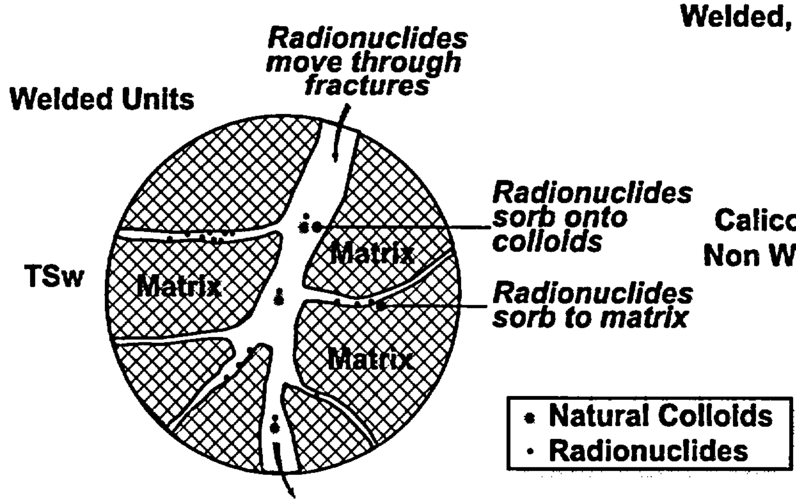
- Initial release of Tc caused by early waste package failure @ 1,000 years
- Tc release reaches a plateau as the rate of waste packages "failing" is ~ linear and the degradation, mobilization and transport are relatively rapid
- Tc release is variable reflecting waste package failure distribution
- Np release continually increases (until the changes back to a dry climate at ~95,000 years) due to adding the releases from additional waste packages as they "fail"

Unsaturated Zone Radionuclide Transport

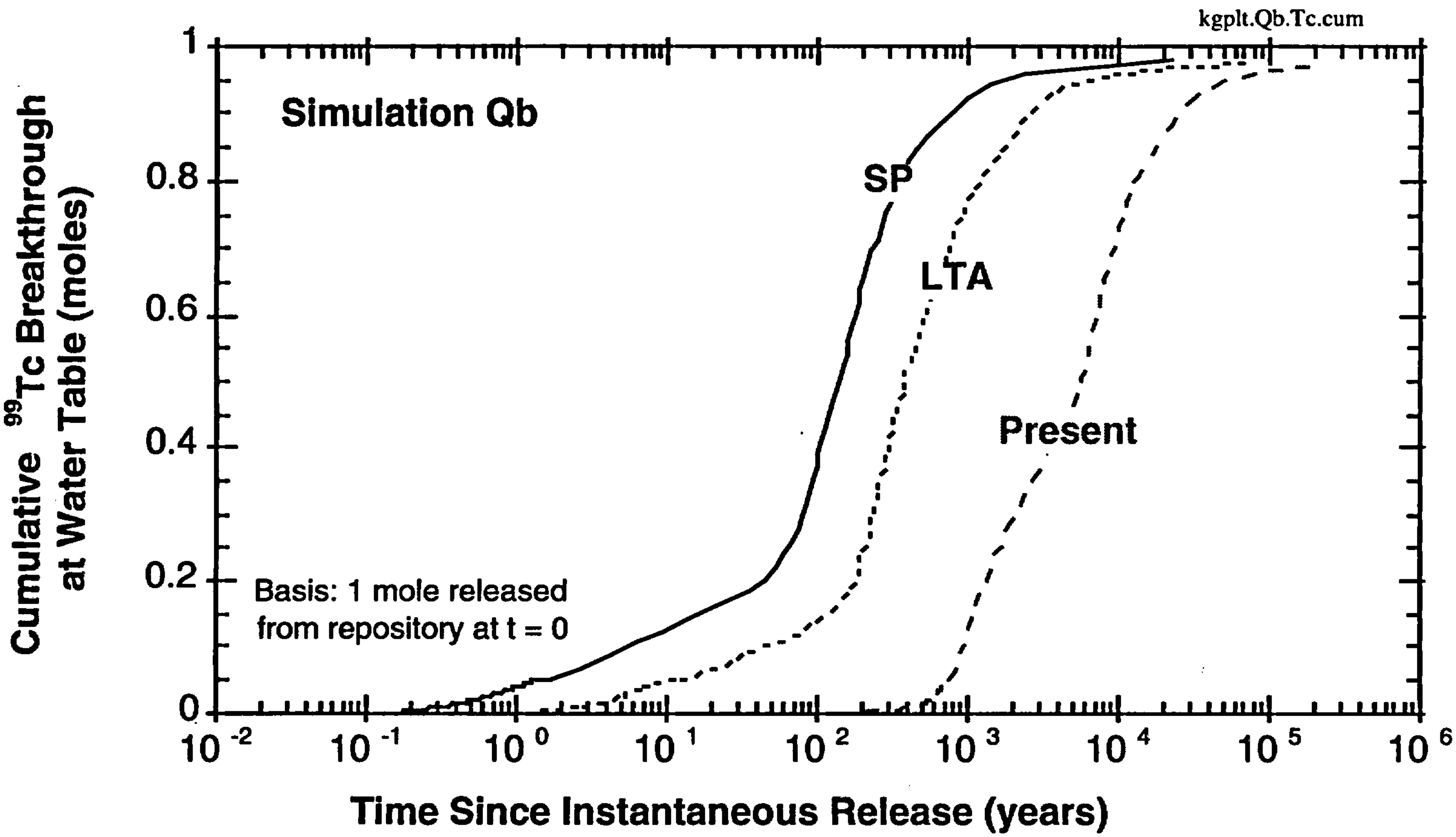


Unsaturated Zone Radionuclide Transport Mechanisms





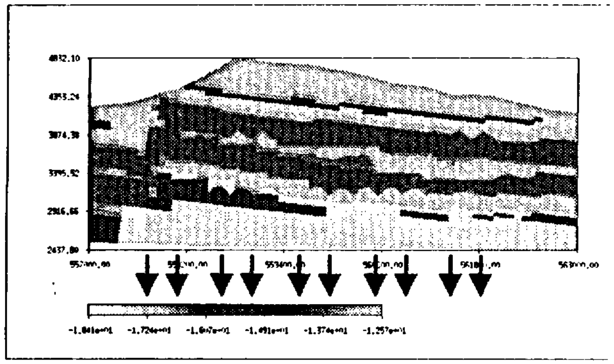
TSPA-VA Base Case
Unsaturated Zone Transport

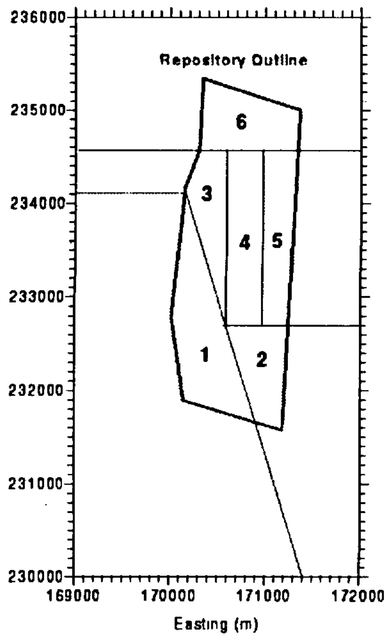


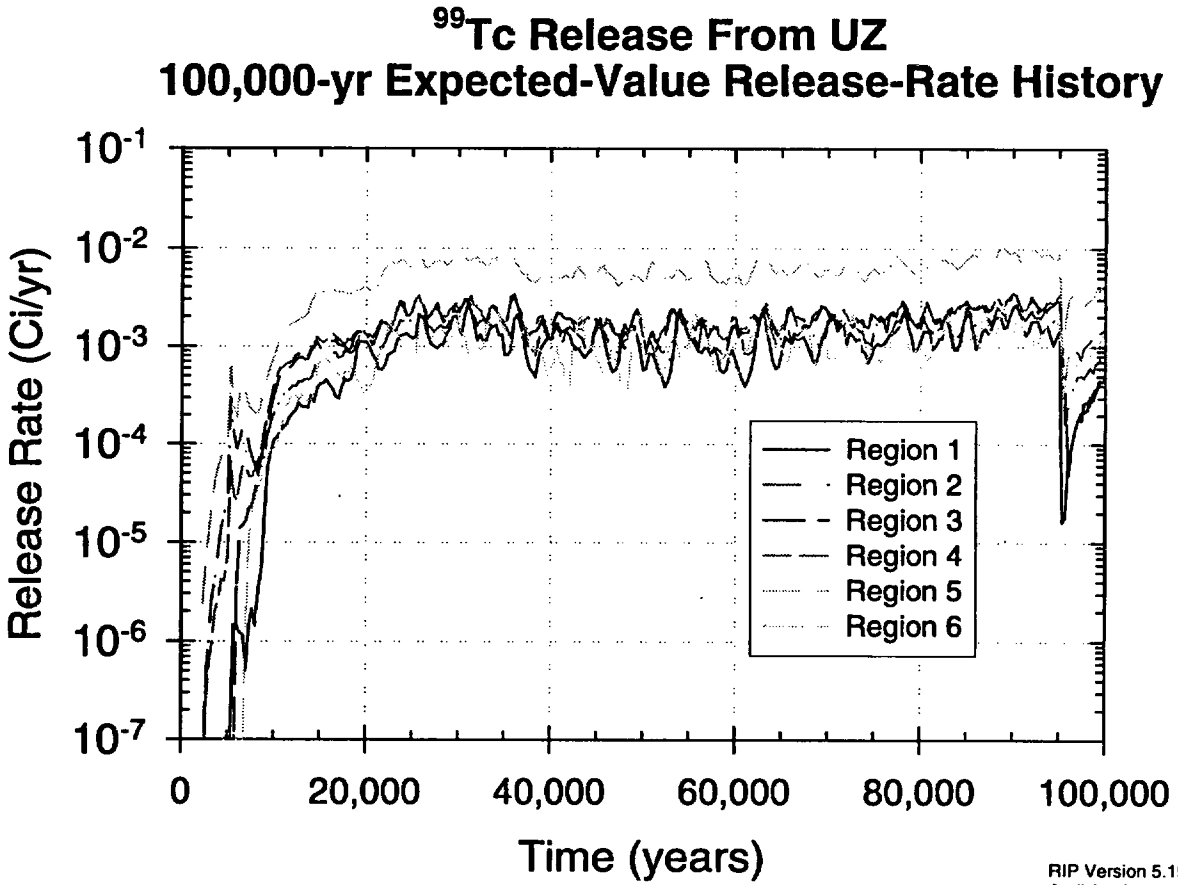
TSPA-VA Base Case
Unsaturated Zone Transport

- Present-day travel time of 50% arrival is ~ 10,000 years for unretarded species (Tc)
- Present-day early arrival a result of small fraction of fracture flow in non-welded Calico Hills (or bypassing)
- Long-term average climate travel times are <1,000 years to the water table for unretarded species
- Sorption coefficients derived from laboratory data

100,000-yr ^{99}Tc Release Rate from UZ to SZ by Region







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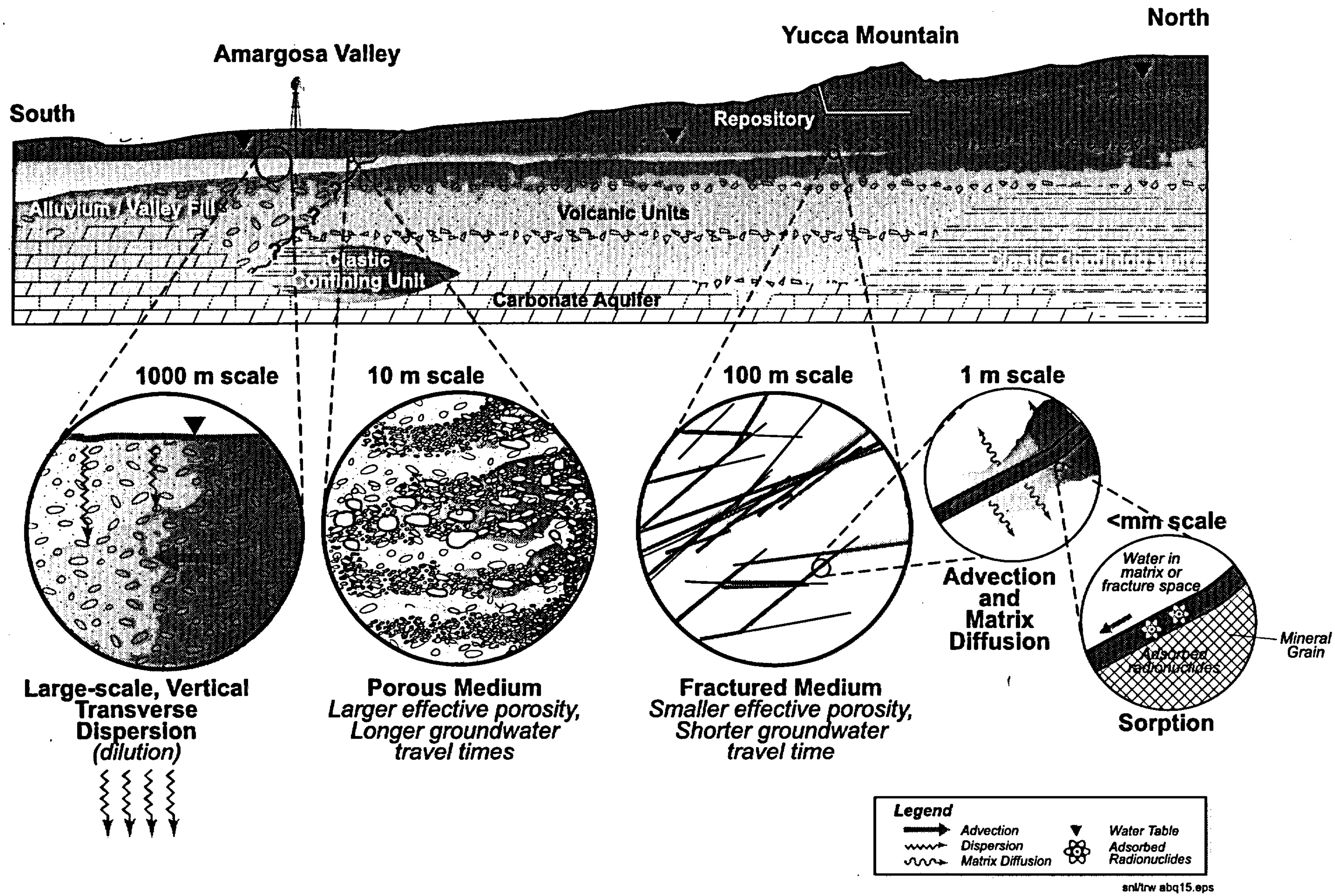
TSPA-VA Base Case Unsaturated Zone Transport: Release Rates from the UZ to the SZ

- Release rates into six regions of the SZ
- Similarity with EBS release rates indicates minimal travel time through UZ for unretarded species
- Irregularities in Tc release rates correlate with discrete waste package "failures"
- Reduction in release rates at 95,000 years caused by change back to dry climate and corresponding water table lowering

Saturated Zone Radionuclide Transport



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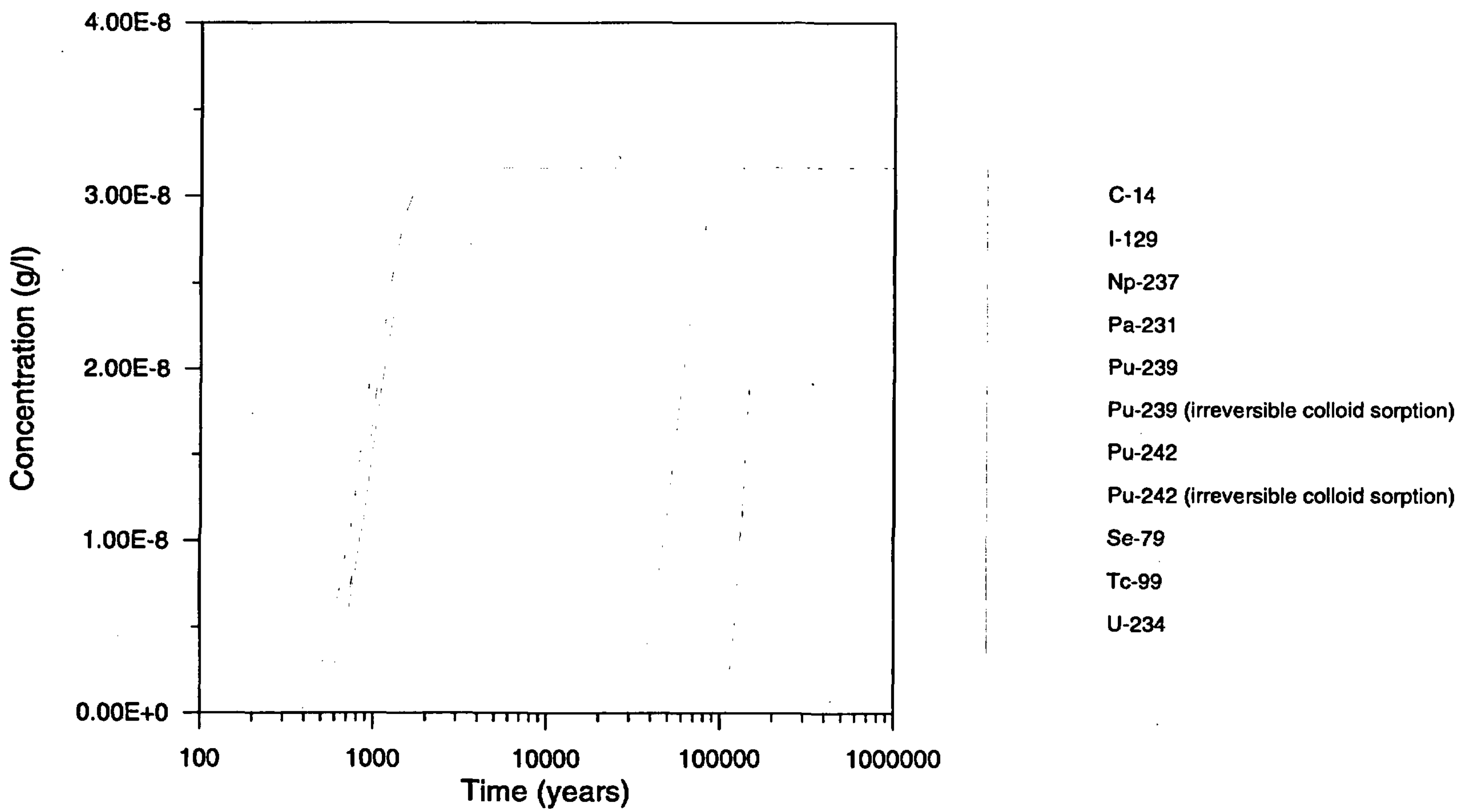
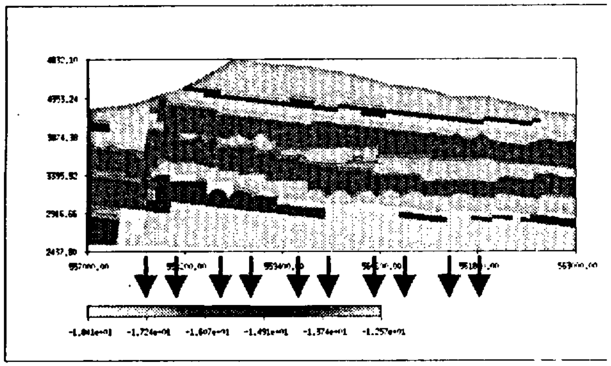
Example TSPA-VA Base Case Saturated Zone Transport

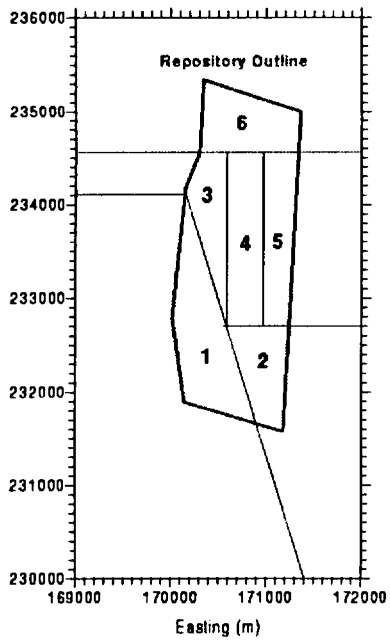


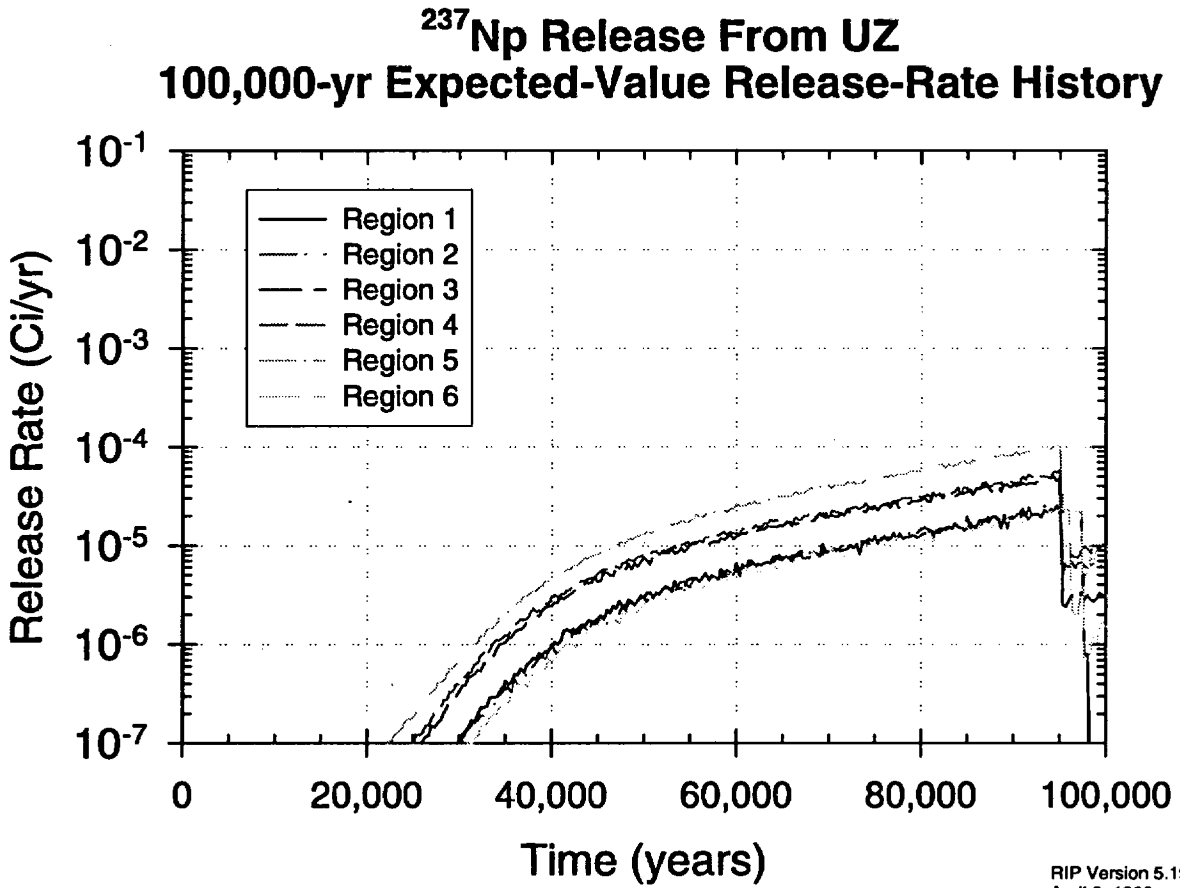
TSPA-VA Base Case
Saturated Zone Transport

- Use 3-D flow and transport model to define general flow paths and rates and fraction of path in alluvium to 20km
- Use six 1-D (stream tubes) model with no transverse dispersivities
- Use an effective dilution factor (ranging from 1-100)
- Compare results of single stream tubes without dilution to multiple stream tubes with dilution
- Travel times in saturated zone range from a few 1,000 years for unretarded species (~Tc) to > 10,000 years for slightly retarded species (~Np)

100,000-yr ^{237}Np Release Rate from UZ to SZ by Region







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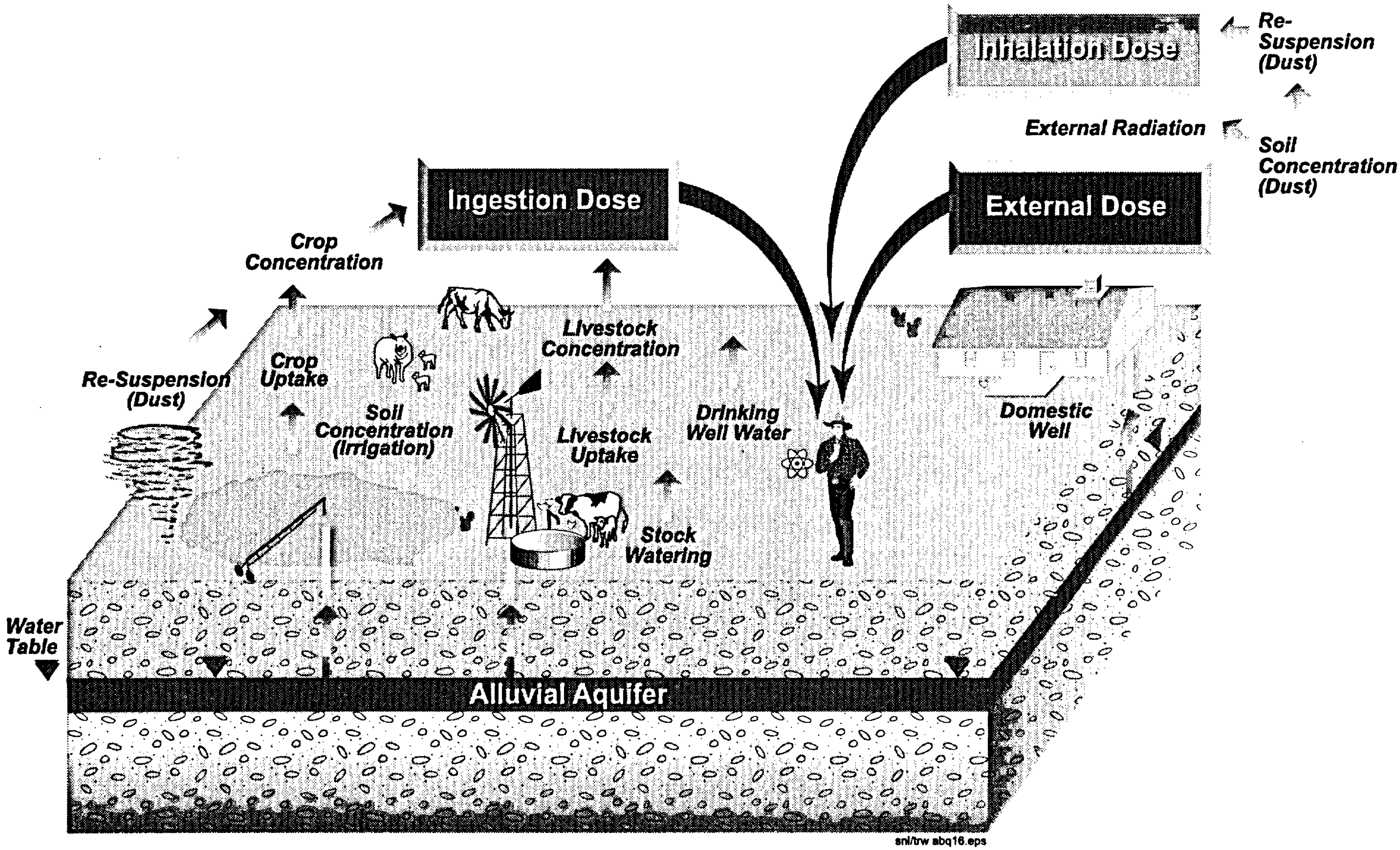
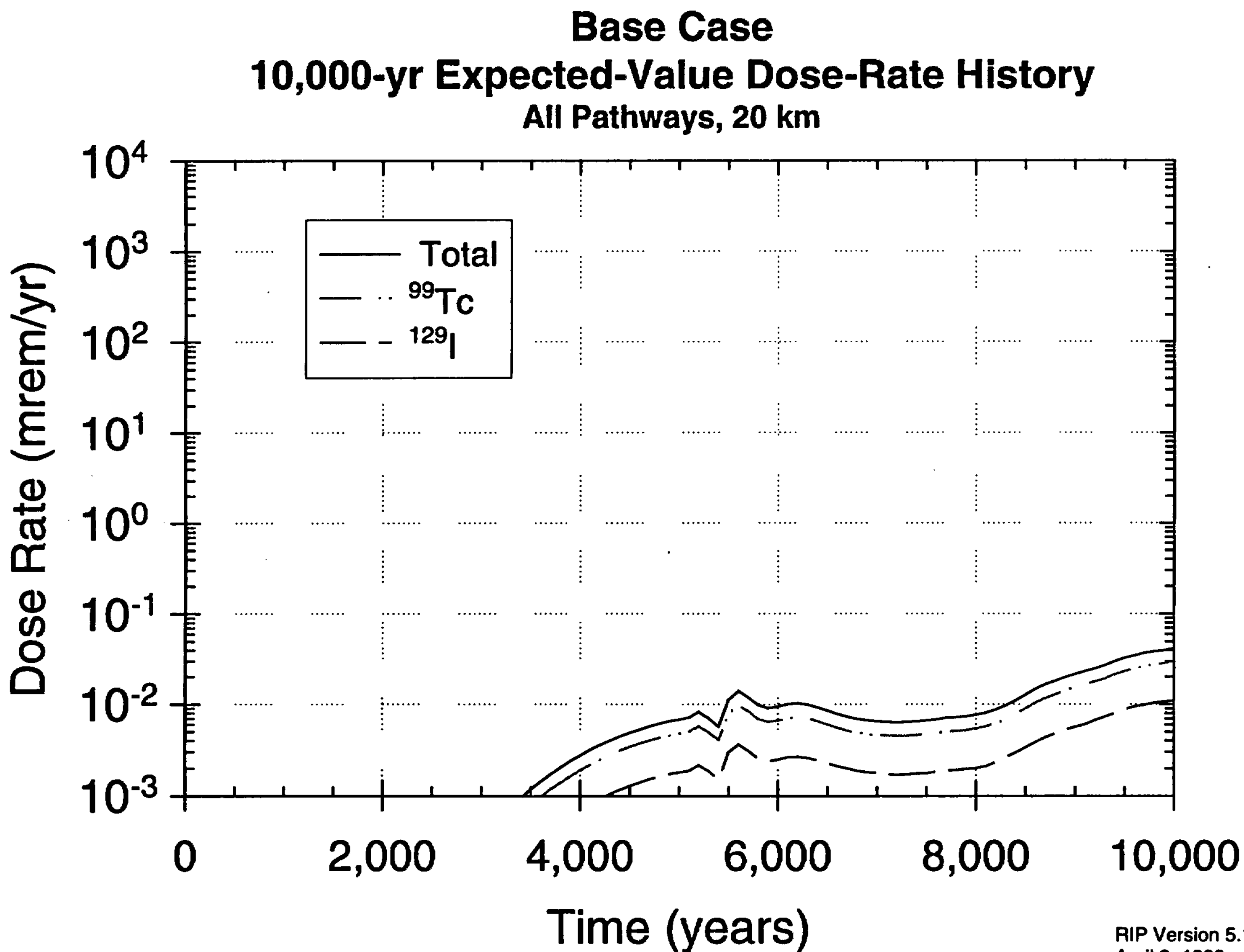
Biosphere Processes in TSPA-VA



10,000-yr Dose to "Average" Individual at 20 km



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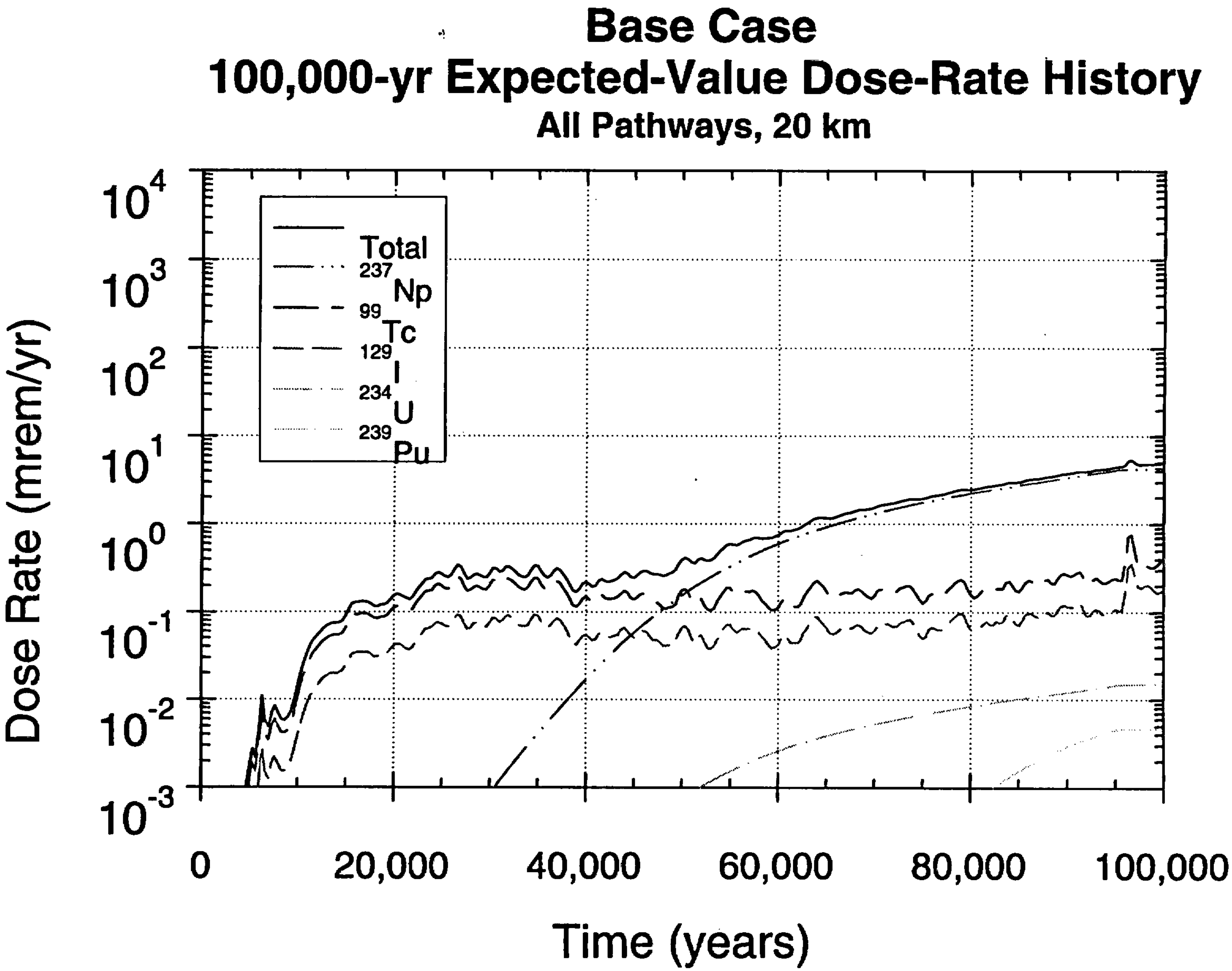
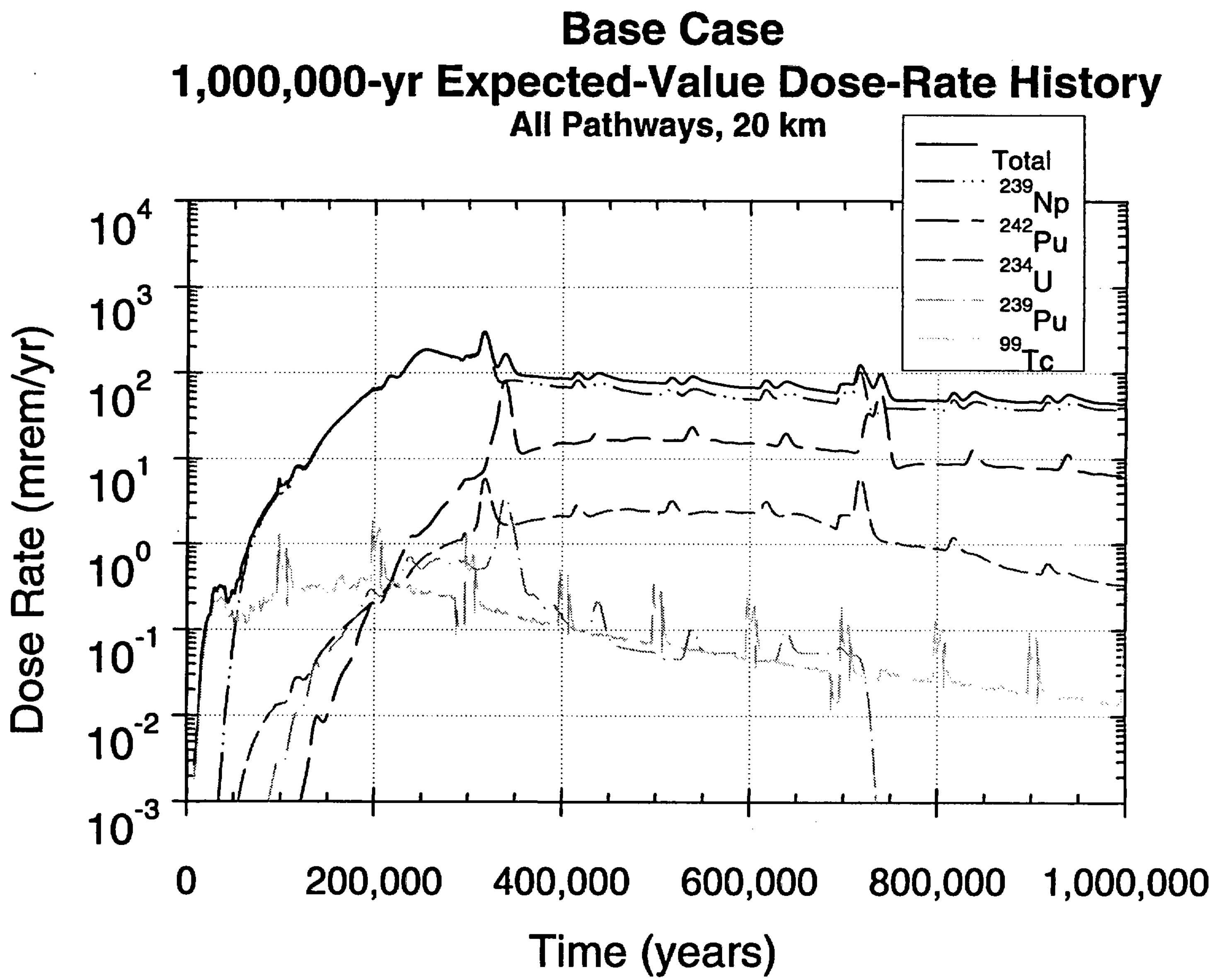
100,000-yr Dose to "Average" Individual at 20 km



1,000,000-yr Dose to "Average" Individual at 20 km



TSPA-VA Base Case Results

- Earliest doses (<10,000 years) are controlled by early waste package "failure" (~ 1,000 years)
- From 10,000 to ~50,000 years the doses are controlled by Tc and I and mimic the shape of the EBS release curves
- For times >50,000 years Np controls the doses and they continue to increase as (a) more waste packages "fail" and (b) an increased % of the cladding "fails"
- "Maximum" dose at 10,000 years ~10^{-2} mrem/yr
- "Maximum" dose and 100,000 years ~5 mrem/yr
- Rate down @ ~300,000 years ~300 mrem/yr

Example Hand Calculation of Dose Rate at 100,000 Years: Representative Values

Percolation Flux:	~ 0.04 m^3/m^2 yr (=40mm/yr)
	~ $2x10^5$ m^3/yr/repository
Seepage Flux:	~ 0.2 m^3/yr/WP
WP "Failures":	~ 20/1,000 years (dripping)
	~ 1,000/50,000 years (dripping)
Np Solubility:	~ 0.3 g/m^3
WF Surface Exposed:	~ 2%
WF Dissolution Rate:	~ 10^{-3}/yr
EBS Seepage Flux:	~ 0.006 m^3/yr/WP (~ 3% of seepage flux)
SZ "Dilution" Factor:	~ 10
Biosphere Dose Conversion Factor:	~ $5x10^6 \frac{\text{mrem/yr}}{\text{g (Np) /m}^3}$
	~ $5X10^4 \frac{\text{mrem/yr}}{\text{g (Tc)/m}^3}$

Example Hand Calculation of Dose Rates at 100,000 Years for a Solubility-Limited Radionuclide -Np

Np Half Life: 2,000,000 yrs

Np Inventory: 10 Ci/WP (~1.5×10^4 g/WP)

EBS Release Rate: ~ 2×10^{-3} g/yr/WP (0.3 g/m^3 x 0.006 m^3/yr/WP)
~ 2 g/yr/repository (2×10^{-3}g/yr/WP x 1,000 WP)

UZ Concentration: ~ 10^{-5} g/m^3 (2 g/yr/repository ÷ 2×10^5 m^3/yr/repository)
SZ Concentration: ~ 10^{-6} g/m^3 (10^{-5} g/m^3 ÷10)

Dose Rate: ~ 5 mrem/yr (10^{-6} g/m^3 x $5 \times 10^6 \frac{\text{mrem/yr}}{\text{g/m}^3}$)

Postclosure Safety Strategy Attributes	TSPA Model Components	Sensitivity Analyses
Water Contacting Waste Package	Climate	✓
	Infiltration	✓
	Unsaturated Zone Flow-Percolation	✓
	Seepage	✓
	Drips onto Waste Package	
	Thermal Hydrology	
Waste Package Lifetime	Near-Field Geochemical Environment	✓
	Waste Package Degradation	✓
Mobilization Rate of Radionuclides	Cladding Degradation	✓
	Waste Form Degradation	✓
	Seepage Into Waste Package	✓
	Colloid Formation and Stability	✓
	Radionuclide Solubility	✓
	Transport within Waste Package	
Concentration of Radionuclides in ground water	EBS Transport	
	Unsaturated Zone Transport	✓
	Saturated Zone Transport	✓
	Dilution from Pumping	
	Biosphere	✓

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Summary

- Presented conceptual models of processes describing the behavior of the Yucca Mountain repository system
- Described the process model abstractions leading to the base case results of TSPA-VA, illustrating the significant components driving the TSPA-VA results
- Conducted a simple back-of-the-envelope analysis that supports the identification of the key components
- Introduced future talks that will address uncertainty analysis of the TSPA-VA and specific sensitivity analyses of individual components

Backup Slides

Description of Significant Processes

Description of Significant Processes: Climate

Amount of precipitation is a function of:

- Timing and duration of climate change
- Global warming
- Modifications in global temperature and polar ice caps
- Changes in regional and local temperatures and weather patterns

Description of Significant Processes: Infiltration

Rate of water which infiltrates is a function of:

- Duration, frequency, timing and magnitude of precipitation events
- Soil thickness and properties
- Slope angle, roughness and orientation
- Vegetation type and amount
- Bedrock permeability

Description of Significant Processes: Unsaturated Zone Hydrology

Rate which water percolates at repository horizon is a function of:

- Net infiltration
- Lithologic heterogeneity of hydrostratigraphic units
- Permeability of fractures and matrix
- Capillarity of fractures and matrix
- Imbibition of matrix

Description of Significant Processes: Seepage into Drifts

Amount of water which seeps is a function of:

- Percolation flux in fractures intersecting drifts and permeability
- Capillarity and permeability of fractures around drifts
- Changes in percolation flux caused by thermal and climate effects
- Heterogeneity and continuity of fractures around drifts
- Changes in fracture capillarity and permeability caused by thermal mechanical and chemical effects

Description of Significant Processes: Thermal Hydrology in TSPA-VA

Amount of water in contact with waste packages is a function of:

- Thermal design of repository and waste packages
- Percolation flux in rock
- Thermal characteristics of rock
- Fracture characteristics of rock
- Matrix imbibition of rock mass
- Hydrologic characteristics of invert materials

Description of Significant Processes: Near Field Geochemical Environment

Chemical characteristics of water in contact with waste packages and waste form is a function of:

- Initial water composition
- Gas phase evolution
- Water/rock interactions
- Water/waste package materials interactions
- Water/waste form materials interactions
- Water/invert/concrete interactions

Description of Significant Processes: Waste Package Degradation

Timing and extent of openings through waste package are a function of:

- Thermal, hydrologic (esp. seeps) and chemical environment on outer surface
- Corrosion rates of mild steel
- Thermal, hydrologic (esp. seeps) and chemical environment of C-22 surface
- Variability in corrosion rates from location to location on waste package
- Corrosion rates of C-22

Description of Significant Processes: Cladding Degradation

Timing and extent of openings through cladding are a function of:

- Type of cladding (Stainless steel vs Zircaloy)
- Thermal environment in waste package
- Condition of Zircaloy during handling, transportation, storage
- Creep characteristics of Zircaloy
- Corrosion of Zircaloy
- Mechanical degradation of Zircaloy

Description of Significant Processes: Waste Form Degradation

Rate of radionuclide release from waste form to water is a function of:

- Characteristics of waste form
- Percent of waste form surface exposed and in contact with water
- Chemistry of water in contact with waste form
- Presence of secondary phases that form during dissolution

Description of Significant Processes: Radionuclide Mobilization

Concentration of radionuclides available for release from waste form is a function of:

- Chemistry and amount of water in contact with waste form
- Presence of secondary phases that form during dissolution
- Concentration of colloidal particles
- Radionuclide solubilities

Description of Significant Processes: Engineered Barrier System Transport

Concentration of radionuclides released from EBS is a function of:

- Seepage into drifts, seepage into degraded waste packages and seepage contacting exposed waste form surfaces
- Diffusion through waste package openings and partially saturated invert materials
- Adsorption onto degraded waste package and invert materials

Description of Significant Processes: Unsaturated Zone Transport

Concentration of radionuclides released from UZ is a function of:

- Concentration of radionuclides released from EBS
- Percolation flux distribution in fractures and matrix
- Adsorption onto fracture surfaces or in matrix
- Diffusion between fractures and matrix
- Radioactive decay

Description of Significant Processes: Saturated Zone Transport

Concentration of radionuclides released from SZ is a function of:

- Concentration of radionuclides released from UZ
- Advective velocity of ground water in tuff and alluvial aquifers
- Adsorption in tuff matrix and on alluvial sediments
- Length of travel path in tuff and alluvial aquifers
- Transverse dispersivity in tuff and alluvial aquifers (≈ dilution)
- Water extraction scenarios

Description of Significant Processes: Biosphere

Dose rate for potential receptors is a function of:

- Concentration of radionuclides released from SZ
- Water use and consumption habits of receptors
- Principal pathway of radionuclides from water use to receptors
- Dose conversion factors

YUCCA
MOUNTAIN
PROJECT

Uncertainty/Sensitivity Analysis for TSPA-VA

Presented to
NWTRB
Panel on Performance Assessment: TSPA-VA
Albuquerque, New Mexico

Presented by:
Michael L. Wilson
Sandia National Laboratories
Albuquerque, New Mexico

April 23-24, 1998

Acknowledgements

- Robert J. MacKinnon
  Sandia National Laboratories
- B. S. RamaRao
  Duke Engineering & Services

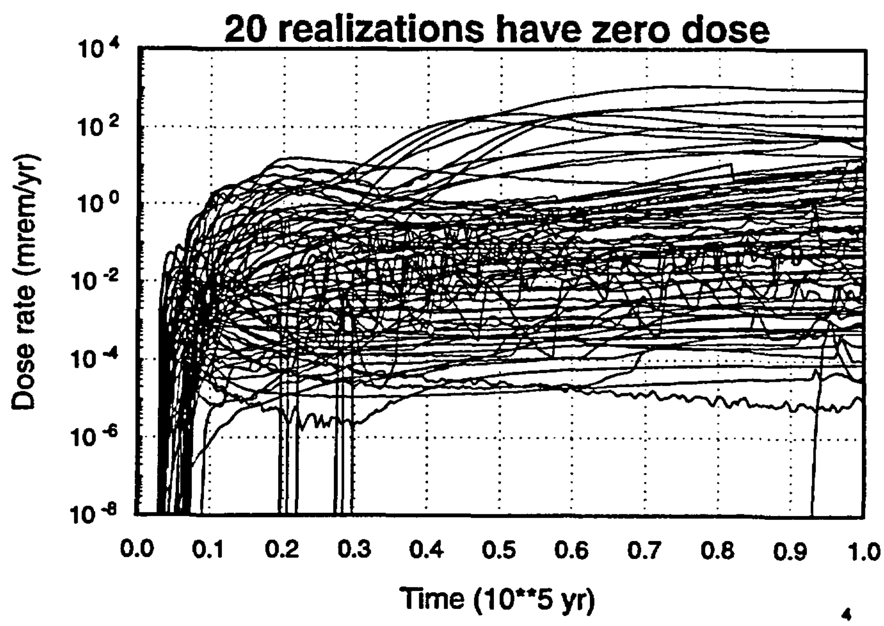
2

Uncertainty Analysis

- Uncertainty analysis is used to quantify the uncertainty in the system
- Our primary method of uncertainty analysis is Monte Carlo simulation
- Probability distributions are assigned to uncertain input variables, and a resulting probability distribution of the performance measure is computed
- Performance distribution is usually presented as a CCDF (complementary cumulative distribution function) on a log-log plot, which emphasizes the high-release tail
- Peak individual dose rate at 20-km distance is the performance measure being used
- Most simulations are being done for 100,000 years, with some for 10,000 years or 1,000,000 years

3

80 Dose Time Histories for the Base Case



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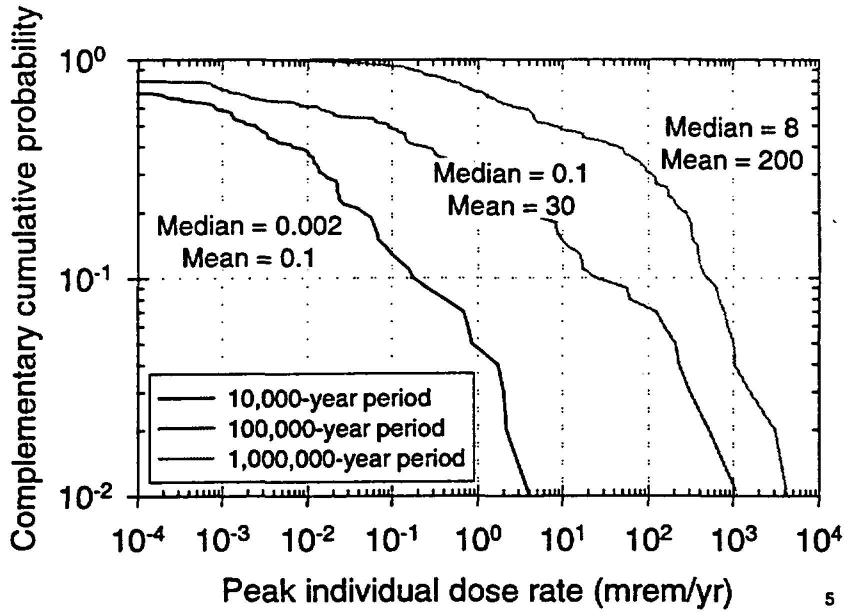
Base Case CCDFs of Peak Dose Rate



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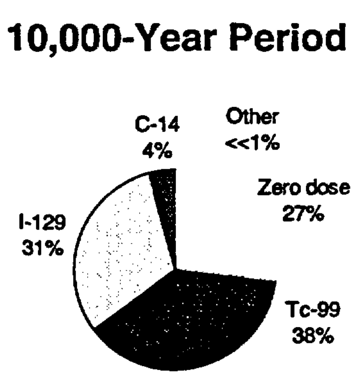
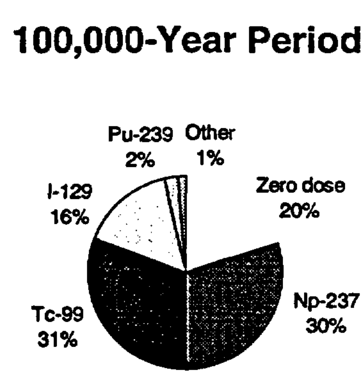
Average Radionuclide Contribution to Peak Dose Rate





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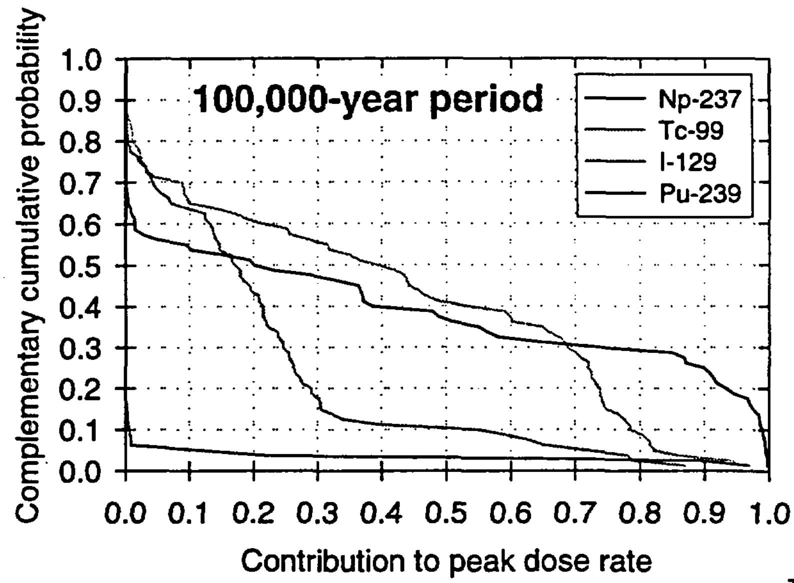
Radionuclide Contribution to Peak Dose



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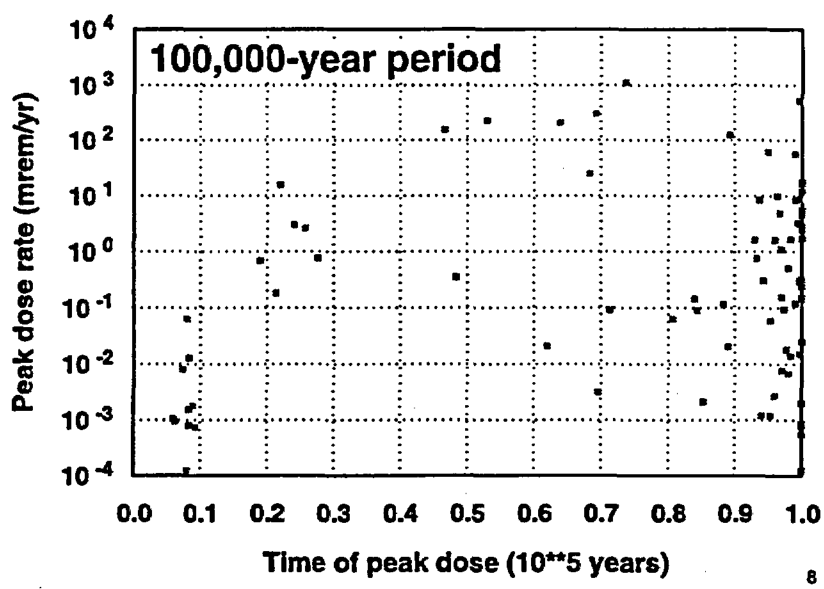
Scatter Plot of Peak-Dose Time



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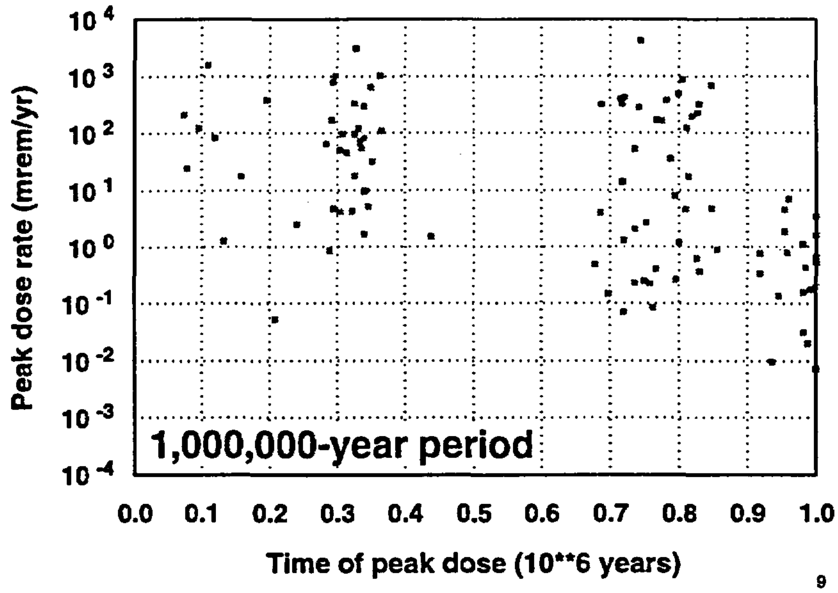
Scatter Plot of Peak-Dose Time



9

Sensitivity Analysis

- Sensitivity analysis is used to
  - Rank uncertain inputs according to their effect on repository performance measures
  - Guide future model development and data acquisition
  - Check consistency in results that are transferred between models

10

Sensitivity Analysis (cont.)

- Sensitivity-analysis methods include
  - Scatter plots of Monte Carlo results
  - Stepwise regression analysis, primarily using rank values
  - Importance ranking of uncertain variables by partial correlation coefficients (PCCs), standardized regression coefficients (SRCs), and contribution to variance (ΔR^2s)
  - "One-off" sensitivity cases, in which all inputs are held constant except for one (or a related group of inputs)
  - Analysis of time histories of releases and/or concentrations of radionuclides at the waste-form/EBS interface, EBS/UZ interface, UZ/SZ interface, and at the receptor
  - Time histories of PCCs for important parameters

Most Important Parameters—10,000 Years

- Rank regression analysis of the base-case results shows the peak dose rate over a 10,000-year period to be most sensitive to:
  - Fraction of waste packages contacted by seeps (PCC = 0.68)
  - C-22 mean corrosion rate (PCC = 0.62)
  - Number of juvenile container failures (PCC = 0.60)
  - Saturated-zone dilution factor (PCC = −0.42)
  - Percolation flux (PCC = −0.37)

PCC = rank partial correlation coefficient with peak dose rate

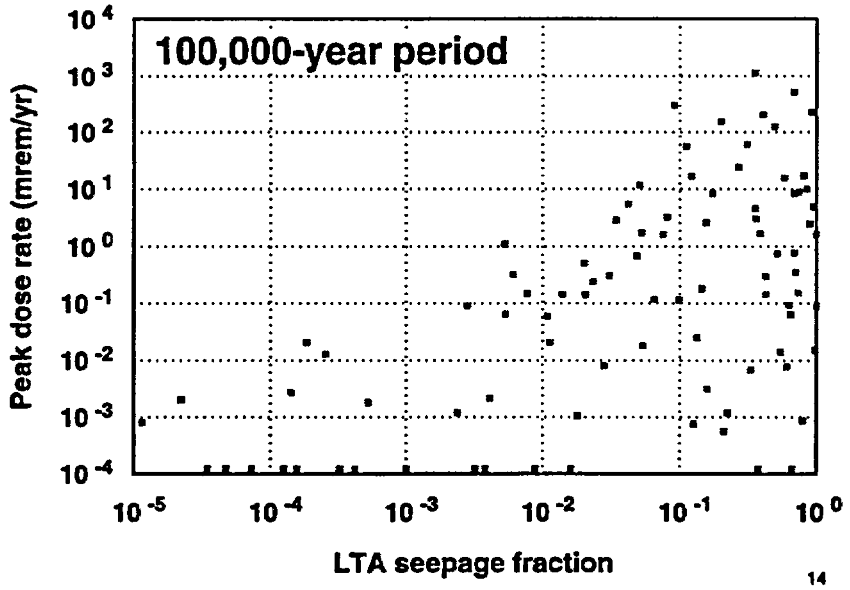
Most Important Parameters—100,000 Years

- Rank regression analysis of the base-case results shows the peak dose rate over a 100,000-year period to be most sensitive to:
  - Fraction of waste packages contacted by seeps (PCC = 0.77)
  - C-22 mean corrosion rate (PCC = 0.70)
  - C-22 corrosion-rate variability (PCC = 0.49)
  - Number of juvenile container failures (PCC = 0.36)

PCC = rank partial correlation coefficient with peak dose rate

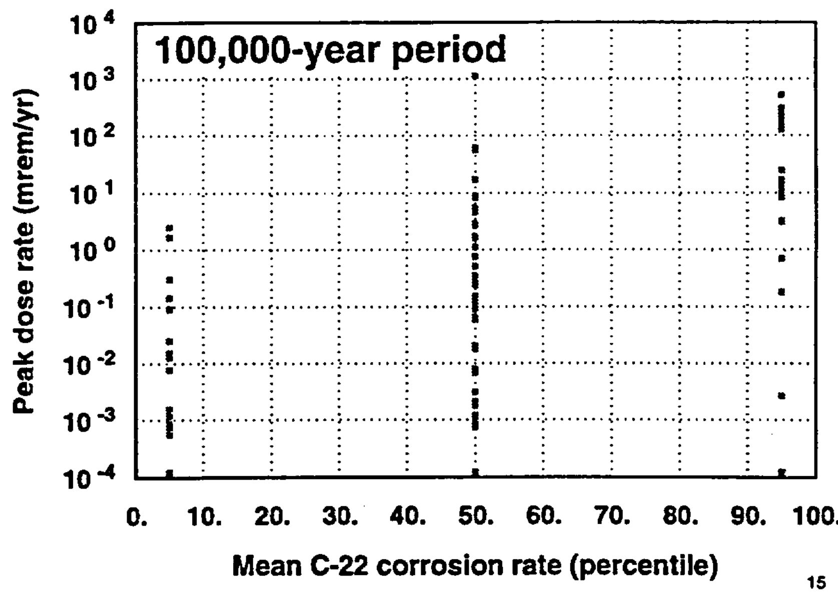
13

Scatter Plot of Seepage Fraction



14

Scatter Plot of C-22 Corrosion Rate



15

Most Important Parameters—1,000,000 Years

- Rank regression analysis of the base-case results shows the peak dose rate over a 1,000,000-year period to be most sensitive to:
  - Fraction of waste packages contacted by seeps (PCC = 0.86)
  - Saturated-zone dilution factor (PCC = –0.56)
  - Biosphere dose-conversion factors (PCC = 0.51)
  - C-22 mean corrosion rate (PCC = 0.41)

PCC = rank partial correlation coefficient with peak dose rate
Note that BDCFs for all radionuclides are correlated

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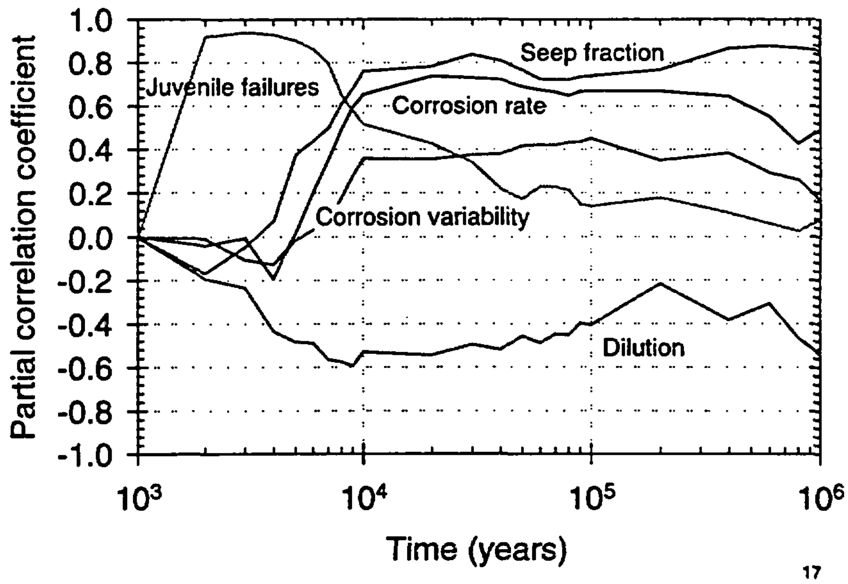
Correlations Versus Time



17

Summary

- ***Dose history can vary considerably, depending on the combination of values of the uncertain parameters.***
- **For 100,000 years of simulation**
  - **Most peak doses occur after 90,000 years. Some of these are not really peaks (i.e., they are still increasing at 100,000 years) and some are local peaks caused by the change from LTA to dry climate.**
  - **Some peaks occur before 10,000 years, caused by juvenile container failures.**
- **For 1,000,000 years of simulation**
  - **Most peak doses are associated with superpluvial climates.**
- **Typically, early doses are dominated by Tc-99 and I-129; late doses are dominated by Np-237.**
- **A few percent of the time, Pu colloids dominate the peak dose.**
- **The most important uncertain parameters depends on the time period. For 100,000 years they are the fraction of waste packages contacted by seeps, the C-22 corrosion rate and its variability, and the number of juvenile failures.**

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YUCCA MOUNTAIN PROJECT

Climate, Infiltration, and UZ Flow for TSPA-VA

Presented to
NWTRB
Panel on Performance Assessment: TSPA-VA
Albuquerque, New Mexico

Presented by:
Jack Gauthier
Sandia National Laboratories
Albuquerque, New Mexico

April 23-24, 1998

Climate

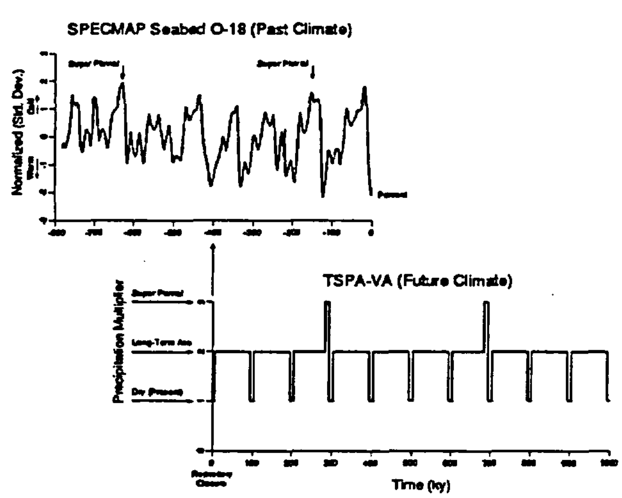
- Affects infiltration, UZ flow (w-t rise), SZ flow (flux), and biosphere components
- Three climate states are represented
  - DRY (similar to present)
  - LTA (long-term average; similar to Santa Fe)
  - SP (super-pluvial; similar to Los Alamos)
- Transition from one state to another is instantaneous
- Over 80% of the sampled time is LTA

2

Climate (contd.)

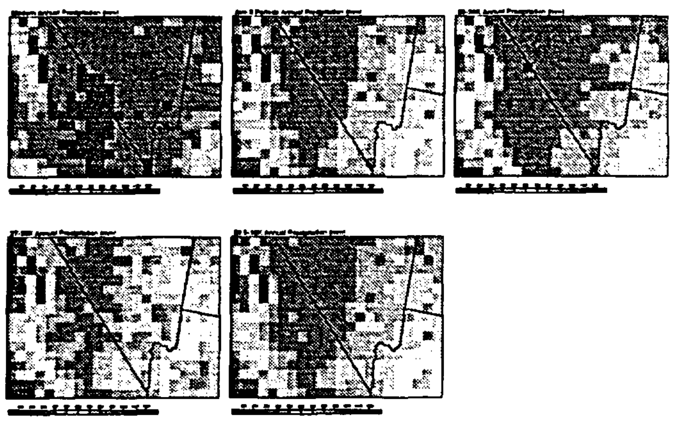
- Climate-change timing based on global paleoclimate record
- Climate magnitude based on local paleoclimate record

SPECMAP Seabed O-18 (Past Climate)



Climate Reconstructions

Yucca Mountain Project Precipitation estimates using Jaccard analog measure and applying anomaly regression to modern grid



Thompson and Anderson (August, 1997)

5

Climate Definition

	DRY	LTA	SP
average precip(mm/yr)	150	300	450
analog site	--	Area 12	South Lake, CA
average infil (mm/yr) I/3 (mm/yr) I*3 (mm/yr)	7 2.3 21	40 13.3 120	120 40 360
duration (ky)	0-20	80-100	0-20
water-table rise (m)	--	80	120
SZ-flux multiplier	--	3.9	6.1

6

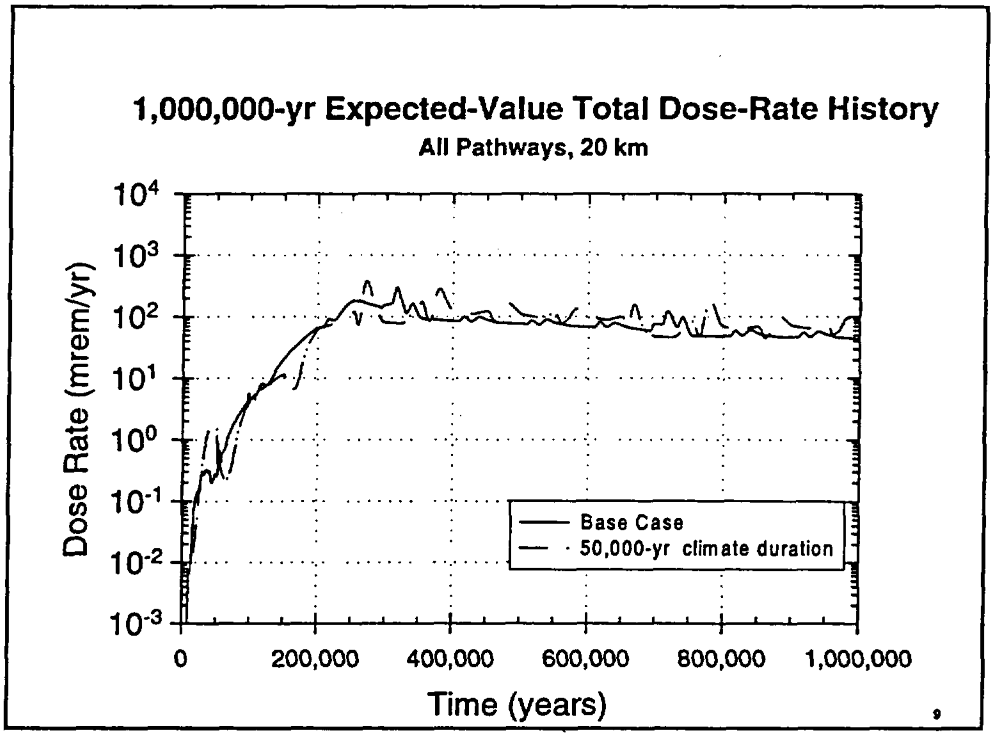
Summary

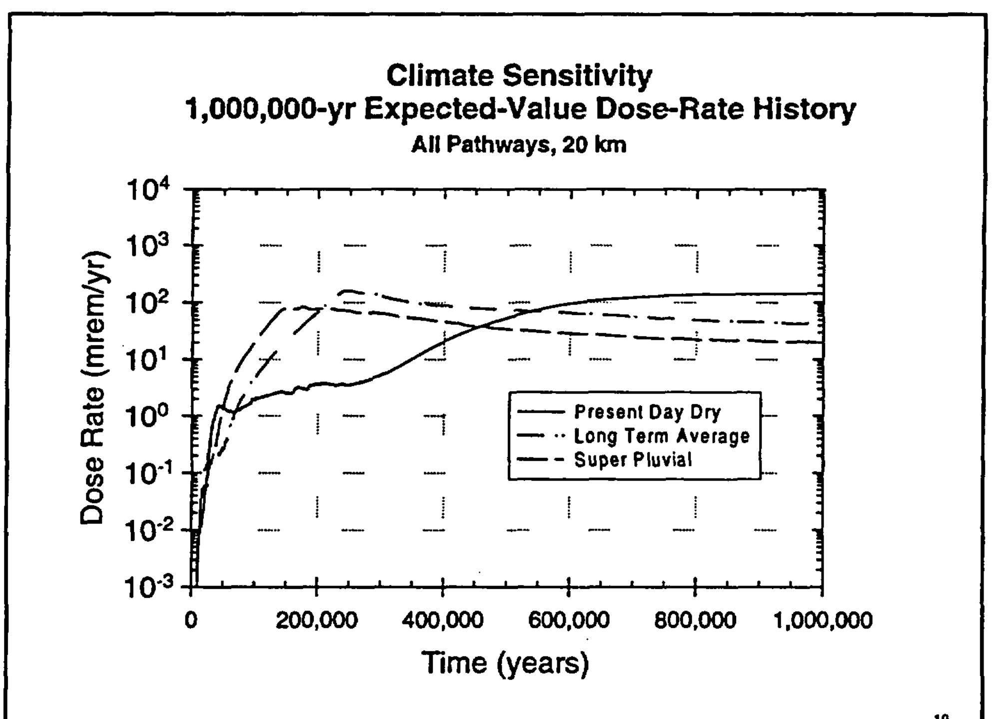
- TSPA-VA base case is primarily an LTA climate with excursions to more extreme states (DRY and SP)
  - DRY (150 mm/yr)
  - LTA (300 mm/yr – like Santa Fe)
  - SP (450 mm/yr – like Los Alamos)
- Uncertainty/variability limited to climate durations and UZ fluxes
  - no water-table-rise uncertainty
  - no SZ-flux uncertainty
  - no biosphere uncertainty

7

Sensitivity Analyses

8


1,000,000-yr Expected-Value Total Dose-Rate History
All Pathways, 20 km
Dose Rate (mrem/yr)
10^4
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
0
200,000
400,000
600,000
800,000
1,000,000
Time (years)
Base Case
50,000-yr climate duration
9


Climate Sensitivity
1,000,000-yr Expected-Value Dose-Rate History
All Pathways, 20 km
Dose Rate (mrem/yr)
10^4
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
0
200,000
400,000
600,000
800,000
1,000,000
Time (years)
Present Day Dry
Long Term Average
Super Pluvial
10

Infiltration

- Affects UZ flow and T-H components.
- Model calculates water balance in the soil profile based on precipitation, evapotranspiration, permeability, and storativity.
- Net infiltration (model output) is the water percolation rate at bedrock or a depth of 6 m in deep alluvium.

11

Infiltration Model Parameters

- Precipitation ***(site and analog records)***
- Temperature ***(site-present day)***
- Cloudiness ***(site-present day)***
- Vegetation ***(site-present day)***
- Slope ***(site)***
- Surface properties ***(estimated)***
- Runoff-infiltration fraction ***(estimated)***

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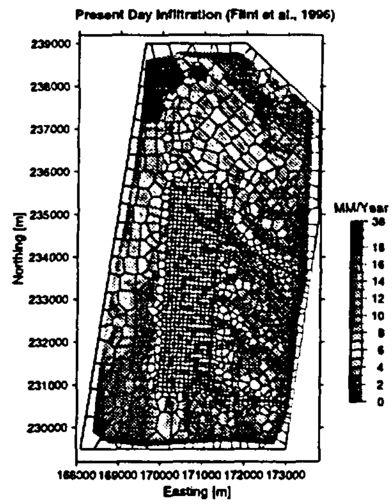
Present Day Infiltration (Flint et al.,1996)



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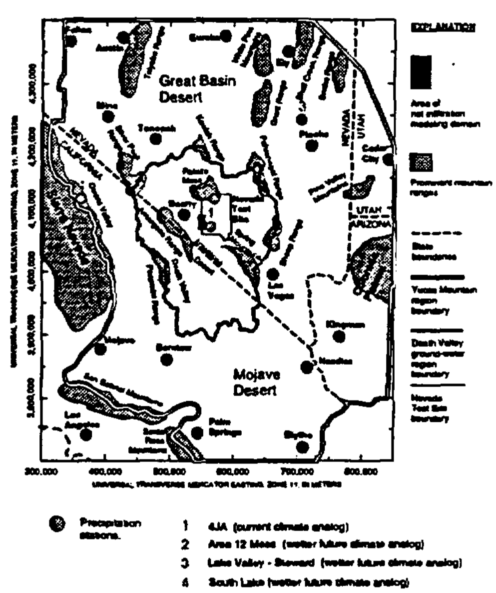

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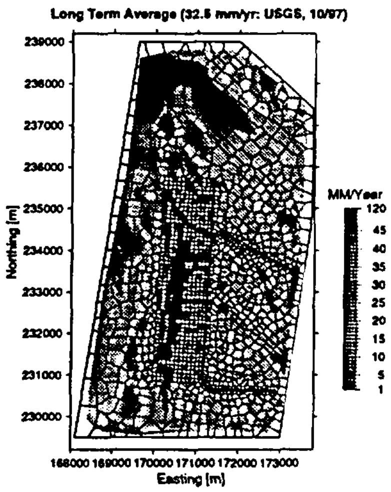
Long Term Average (32.5 mm/yr:USGS, 10/97)



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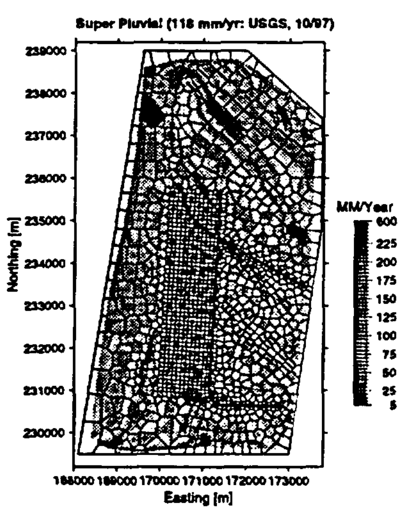
Super Pluvial (118 mm/yr:USGS, 10/97)



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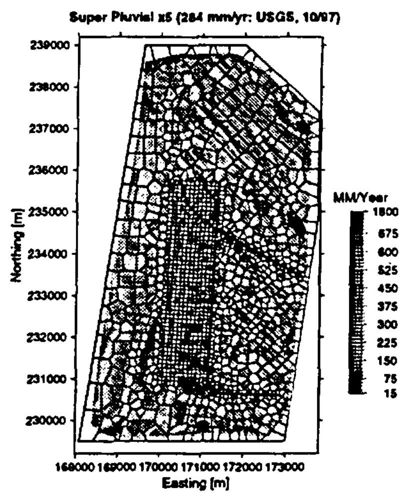

17

Sensitivity Analyses

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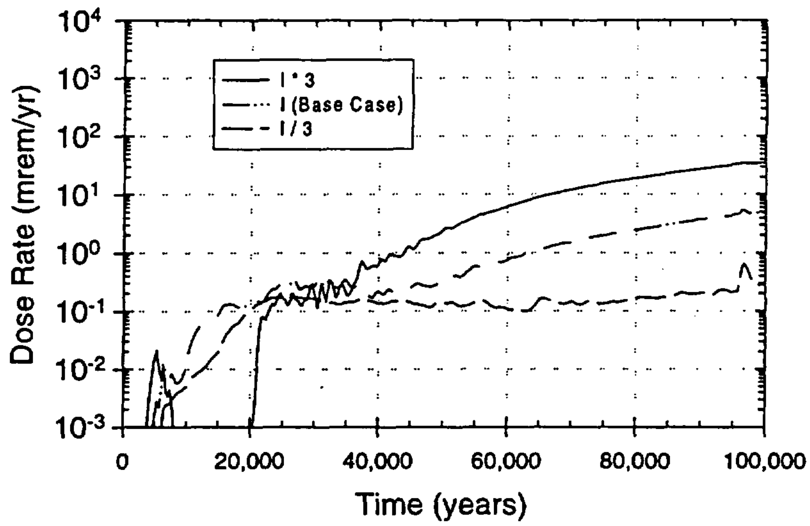
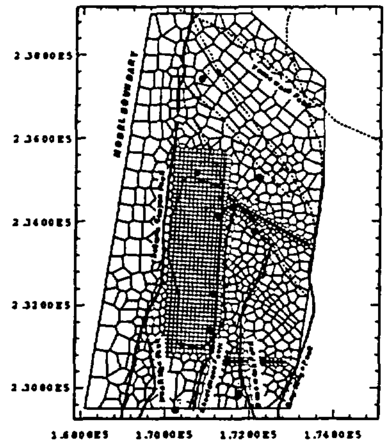
DKM-X_{fm} Infiltration Sensitivity
100,000-yr Expected-Value Dose-Rate History
All Pathways, 20 km



UZ Flow

- Affects seepage and UZ transport components (also, UZ properties are used by the T-H component)
- Model is 3-D, steady-state DKM from LBNL (1997)
- Model is calibrated to S_m, ψ_m, pneumatic data, and perched water, using infiltration maps and site hydrologic-property data
- TSPA calculation samples among discrete flow fields produced by the model

Mountain-Scale UZ Flow Model
(Bodvarsson et al., 1997)



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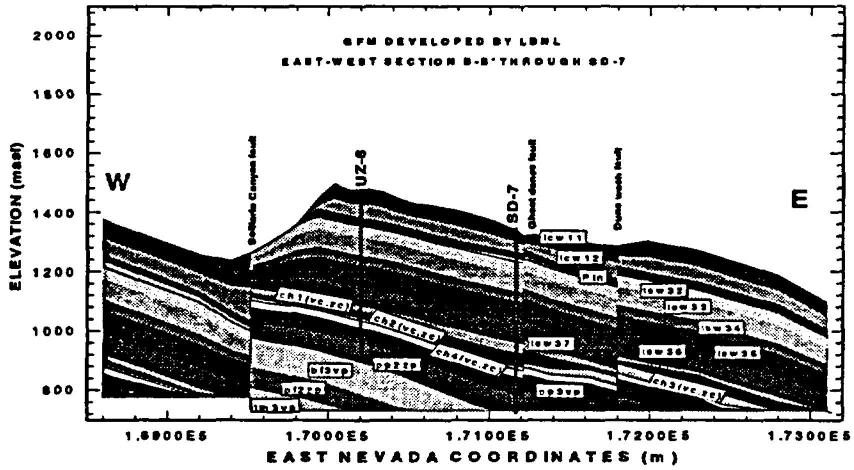
East-West Stratigraphy at SD-7



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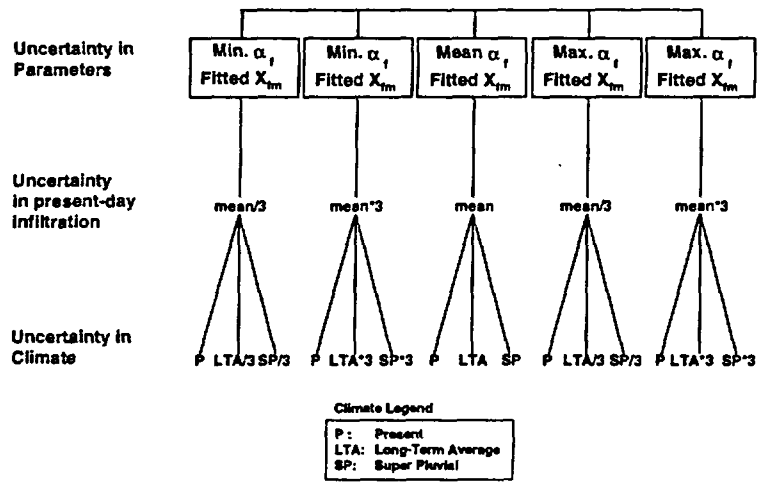
Base-Case UZ-Flow Simulations
(15 Simulations)



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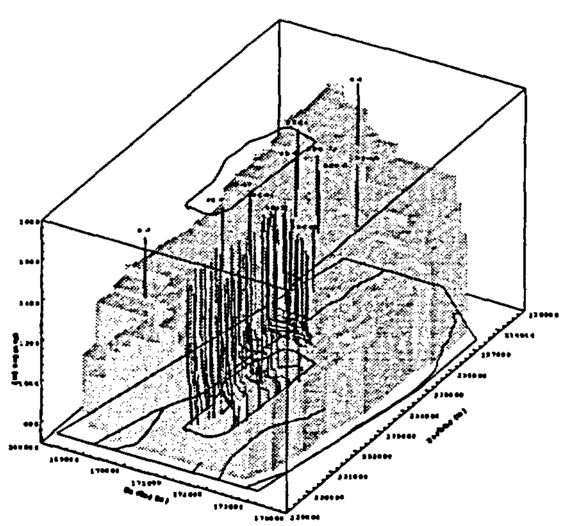
Streamlines for 3-D UZ Flow Field



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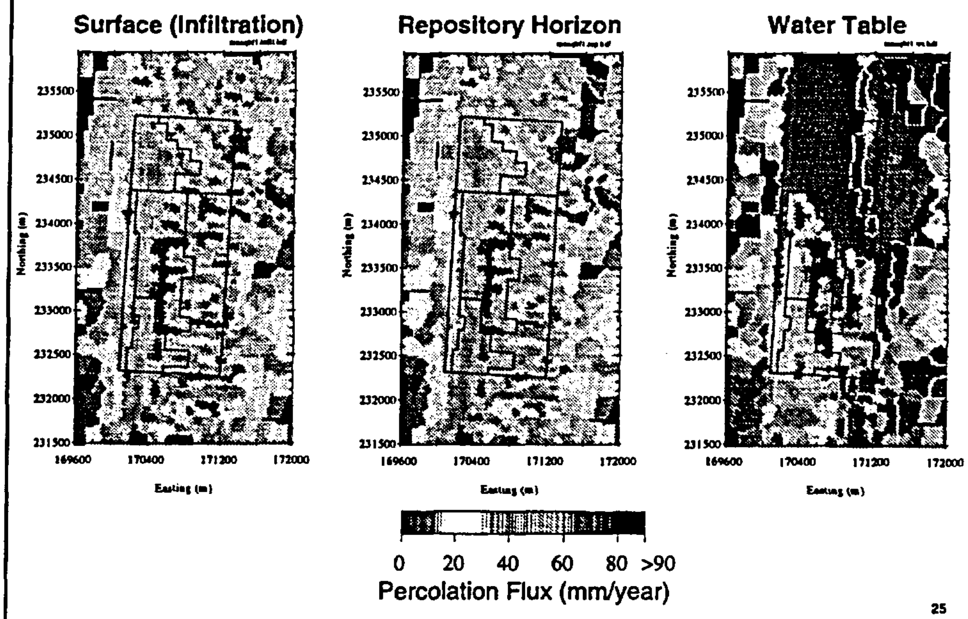
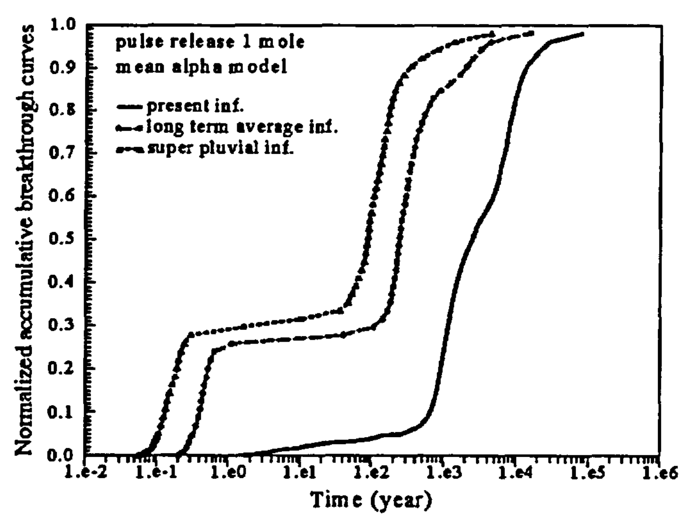
Total (fracture+matrix) Percolation Fluxes

Base-Case Long-Term Average Climate Scenario



25



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SENSITIVITY ANALYSES

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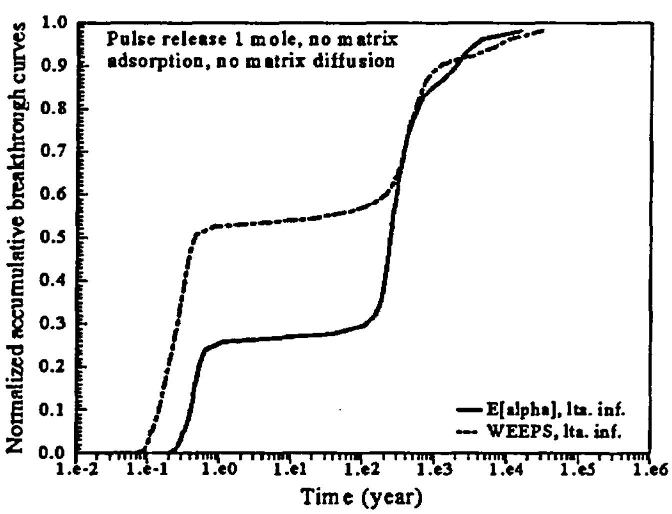

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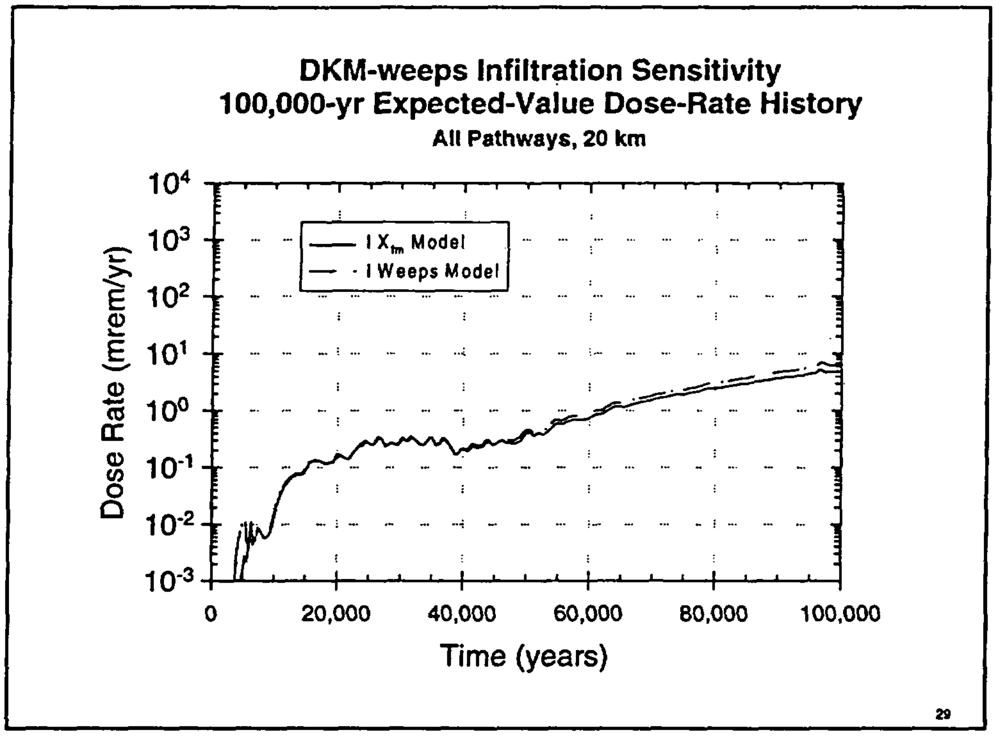

DKM-weeps Infiltration Sensitivity
100,000-yr Expected-Value Dose-Rate History
All Pathways, 20 km
I Xtm Model
I Weeps Model
Dose Rate (mrem/yr)
Time (years)
29

YUCCA
MOUNTAIN
PROJECT

Seepage and Thermal Hydrology for TSPA-VA

Presented to
NWTRB
Panel on Performance Assessment: TSPA-VA
Albuquerque, New Mexico

Presented by:
Michael L. Wilson
Sandia National Laboratories
Albuquerque, New Mexico

April 23-24, 1998

Acknowledgements

- Seepage
  - Chin-Fu Tsang, Guomin Li, Jens Birkholzer
    Lawrence Berkeley National Laboratory
- Thermal hydrology
  - Nicholas D. Francis, Michael T. Itamura, Clifford K. Ho
    Sandia National Laboratories
  - Thomas A. Buscheck, James Gansemer, Truc Delorenzo
    Lawrence Livermore National Laboratory
  - Bryan Dunlap, Srikanta Mishra
    Duke Engineering & Services

2

Seepage Into Drifts

Introduction

- "Seepage" is the liquid water that enters the emplacement drifts.
- Seepage enhances waste-package corrosion, mobilization of radionuclides from the waste form, and transport of radionuclides within the EBS.
- The final results (i.e., doses to individuals) are strongly affected by seepage.
- We parameterize seepage with two quantities:
  - the seepage fraction, or fraction of waste packages contacted by seeps
  - the seep flow rate, or flow rate of water onto those packages that are contacted by seeps
- Seepage is calculated for six repository regions.

4

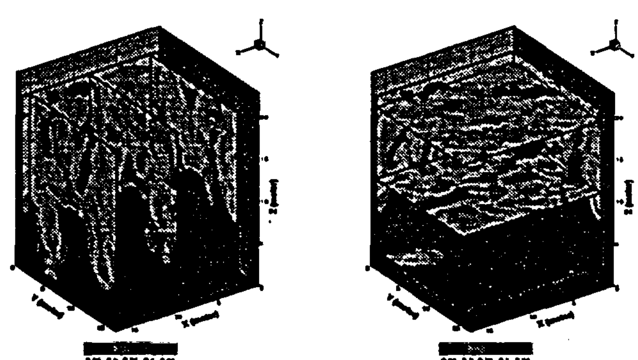
Conceptual Model

- Drifts in unsaturated media can act as capillary barriers, diverting water around them.
- Seepage occurs if rock at the drift wall becomes locally saturated
  - because of disturbance to the flow field caused by the drift opening
  - because of heterogeneities in the permeability field, giving rise to channelized flow and local ponding
- This capillary-barrier effect is confirmed by the ESF niche test.

5

Process Model

- 3-D drift-scale flow model (LBNL)
  - steady state, isothermal
  - no matrix imbibition (fracture continuum only)
  - heterogeneous fracture continuum with 0.5-m grid blocks
  - mechanical, chemical, and thermal alterations assumed to be offsetting or insignificant



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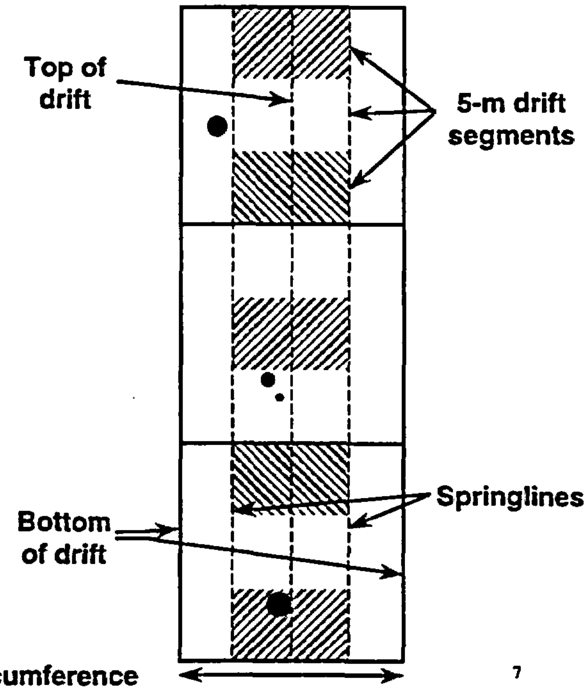
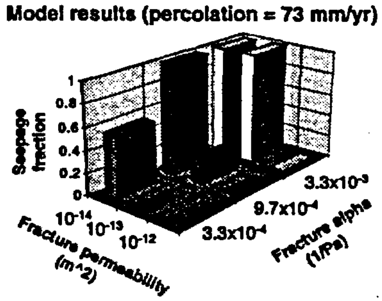
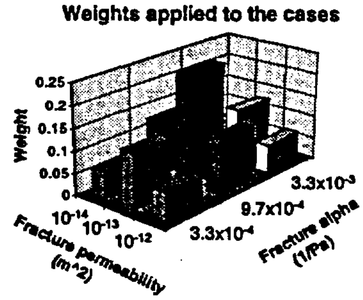
Distribution of Seeps on Drift Wall From 3-D Model

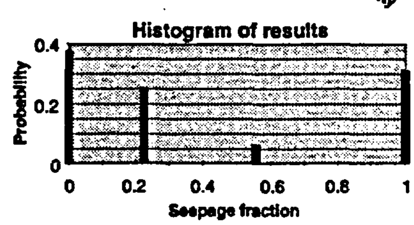


7

Development of Probability Distribution







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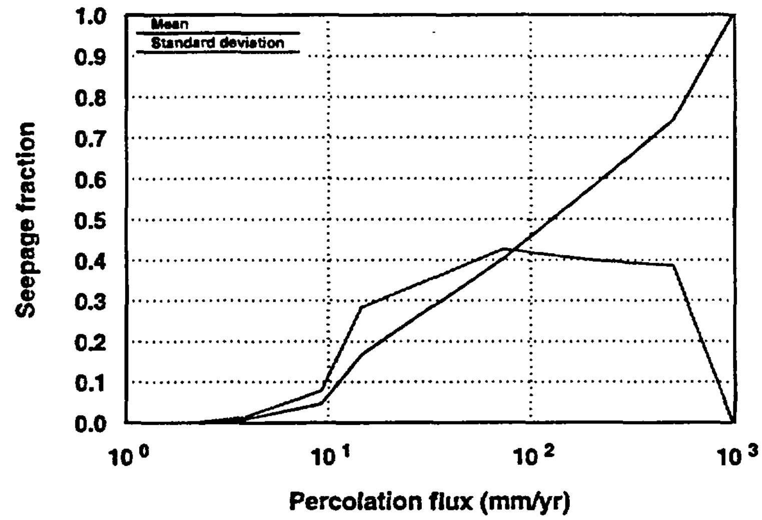
Seepage-Fraction Statistics



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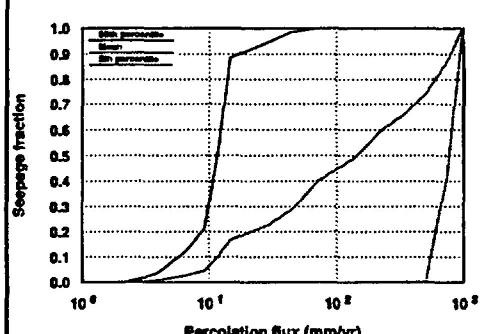
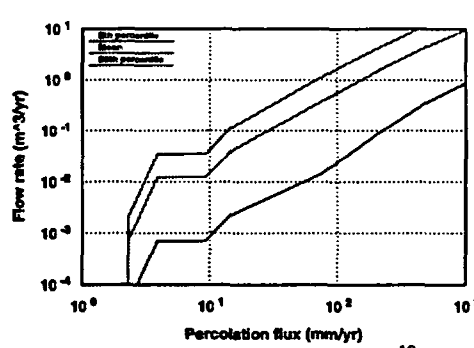
Seepage vs. Percolation Rate





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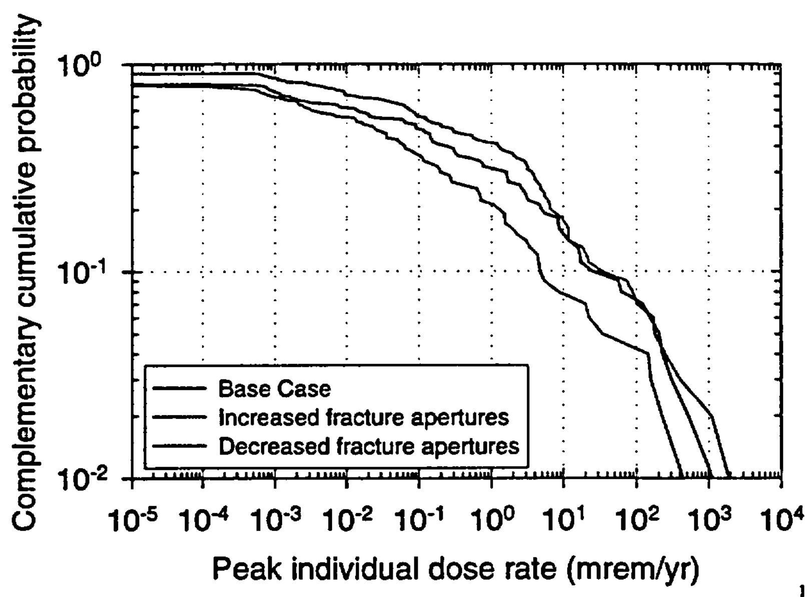
Sensitivity to Fracture-Property Weights



11

Summary

- **Seepage for TSPA-VA is based on a 3-D heterogeneous drift-scale flow model.**
- **Initial comparisons with the ESF niche test are favorable.**
- **Results from nine sets of fracture hydrologic properties are weighted to arrive at the final abstracted model.**
- **Modeled <u>average</u> seepage fraction for present climate is about 3%, for LTA climate is about 25%, and for SP climate is about 40%, with wide uncertainty bands.**
- **For comparison, UZFMEE estimates ranged from less than 1% up to 10% (under present conditions).**
- **Modeled <u>average</u> seep flow rates range from about 20 liters/year (present climate; roughly a drip every couple of minutes) to about 700 liters/year (SP climate; roughly a drip every few seconds).**

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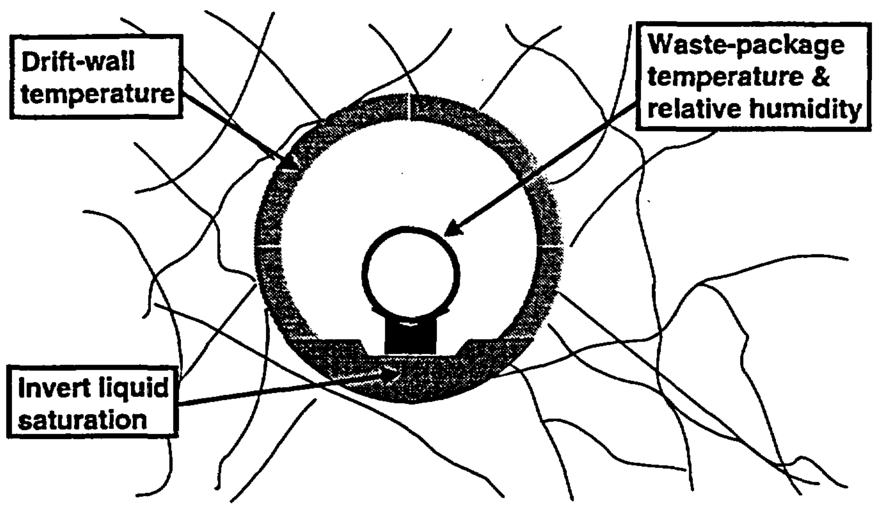
Thermal Hydrology

Introduction

- Drift-scale thermal hydrologic calculations are used to determine the thermodynamic environment (hot, dry, humid, etc.) within emplacement drifts and at waste-package surfaces after the emplacement of heat-generating waste.
- Mountain-scale thermal hydrologic calculations are used to determine the impact of repository heat on large-scale movement of gas and liquid in the mountain.
- Drift-scale calculations must be linked to mountain-scale calculations in order to properly account for dissipation of heat away from the repository.

Quantities From Drift-Scale Model



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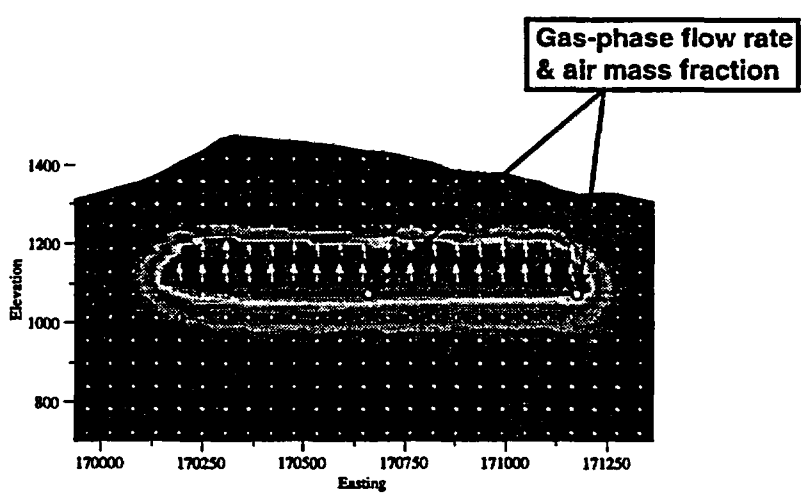
Quantities From Mountain-Scale Model



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Modeling Approach

- Drift-scale T-H models
  - A drift segment with eight waste packages is modeled, to account for variability in WP heat output.
  - The dual-permeability flow model is used.
  - Radiative heat transfer is modeled for open drifts.
  - A series of linked models from mountain scale down to drift scale is used to approximate important dimensional and thermal hydrological effects.
  - An alternative method of linking mountain-scale and drift-scale models is used as a check.
- Mountain-scale T-H models
  - A two-dimensional east-west cross section is used.
  - The equivalent-continuum flow model is used, with reduced matrix satiation to allow greater fracture flow.
- The models include layering and property sets based on the LBNL site-scale unsaturated-zone flow model

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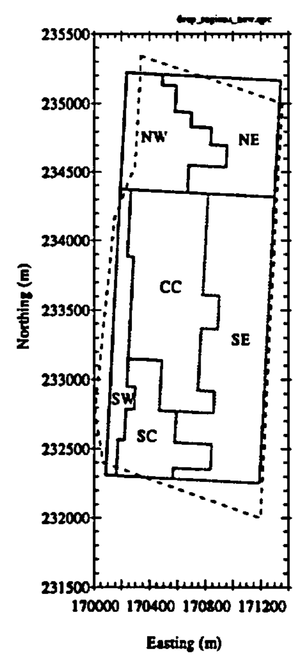
Division of Repository Into Six Regions



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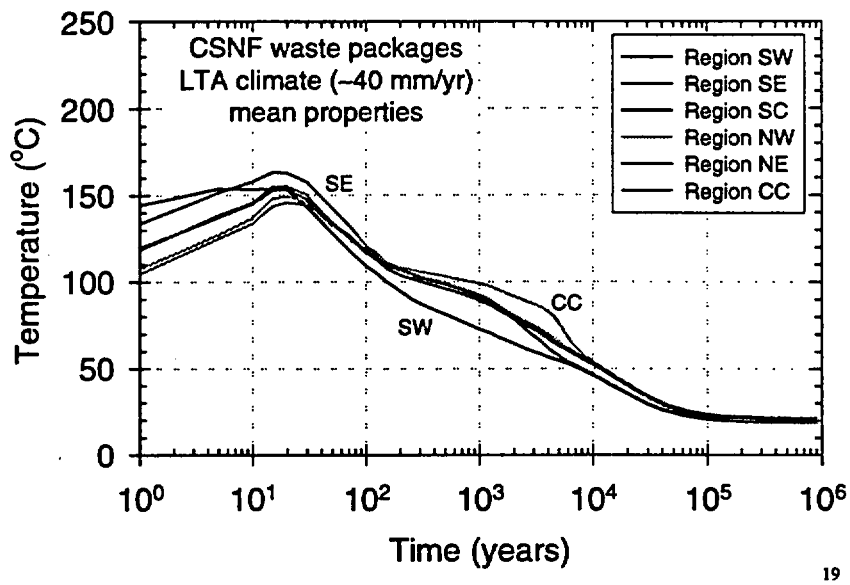
Average Waste-Package Temperature



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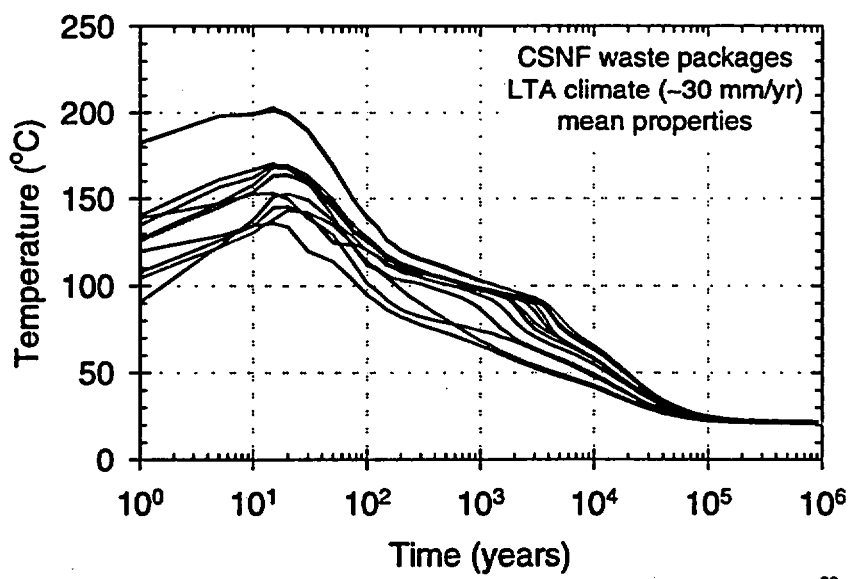
WP Temperature Variability in Region NE



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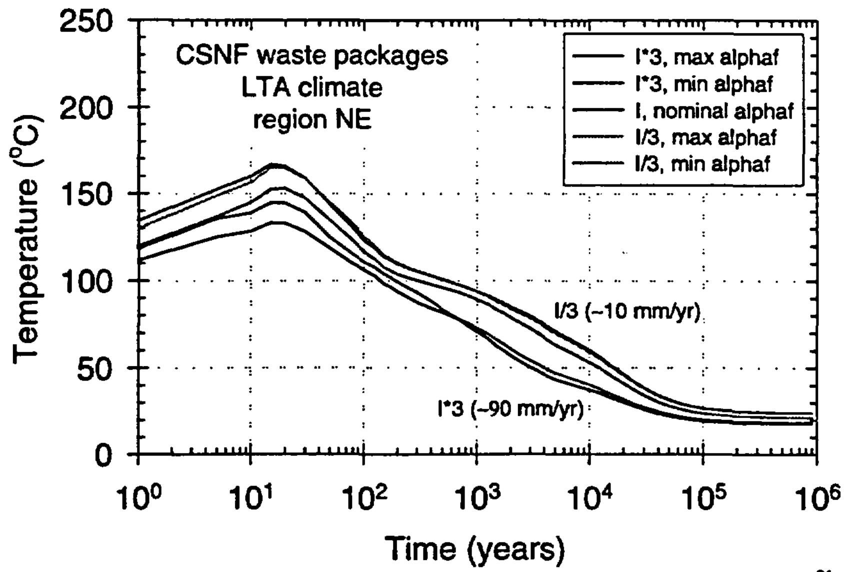
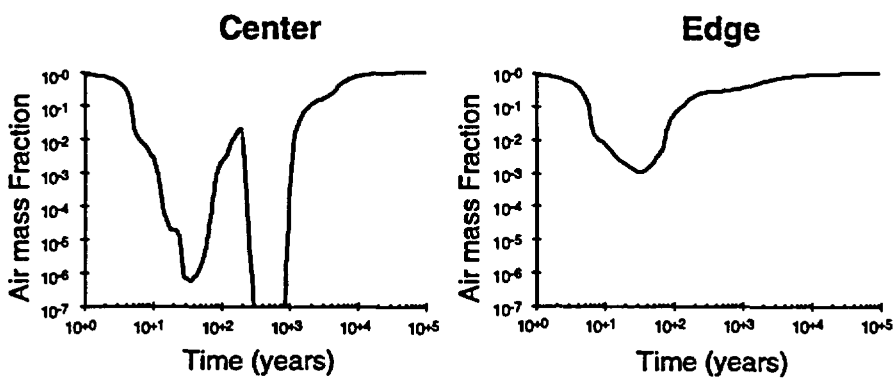
Effect of UZ-Flow Uncertainty



Air Mass Fraction in Repository

present climate (~8 mm/yr)
mean properties



Summary

- Drift-scale T-H quantities are obtained from a multiscale method that accounts for both mountain-scale and drift-scale processes.
- The multiscale modeling approach has been tested against 3-D T-H drift-scale models for repository center and edge locations, with good agreement.
- Gas-phase quantities are obtained from a 2-D mountain-scale T-H model.
- TSPA-VA T-H analyses are performed using conceptual flow models that allow for fracture flow (dual permeability; equivalent continuum with reduced matrix satiation).
- UZ flow/transport and UZ thermal hydrology use consistent hydrologic-property sets.
- Drift seepage is currently calculated within the UZ-flow tasks (i.e., thermal effects on seepage are neglected).

YUCCA MOUNTAIN PROJECT

Studies

Waste Package Degradation

Presented to:
Nuclear Waste Technical Review Board
Performance Assessment Panel
Albuquerque, New Mexico

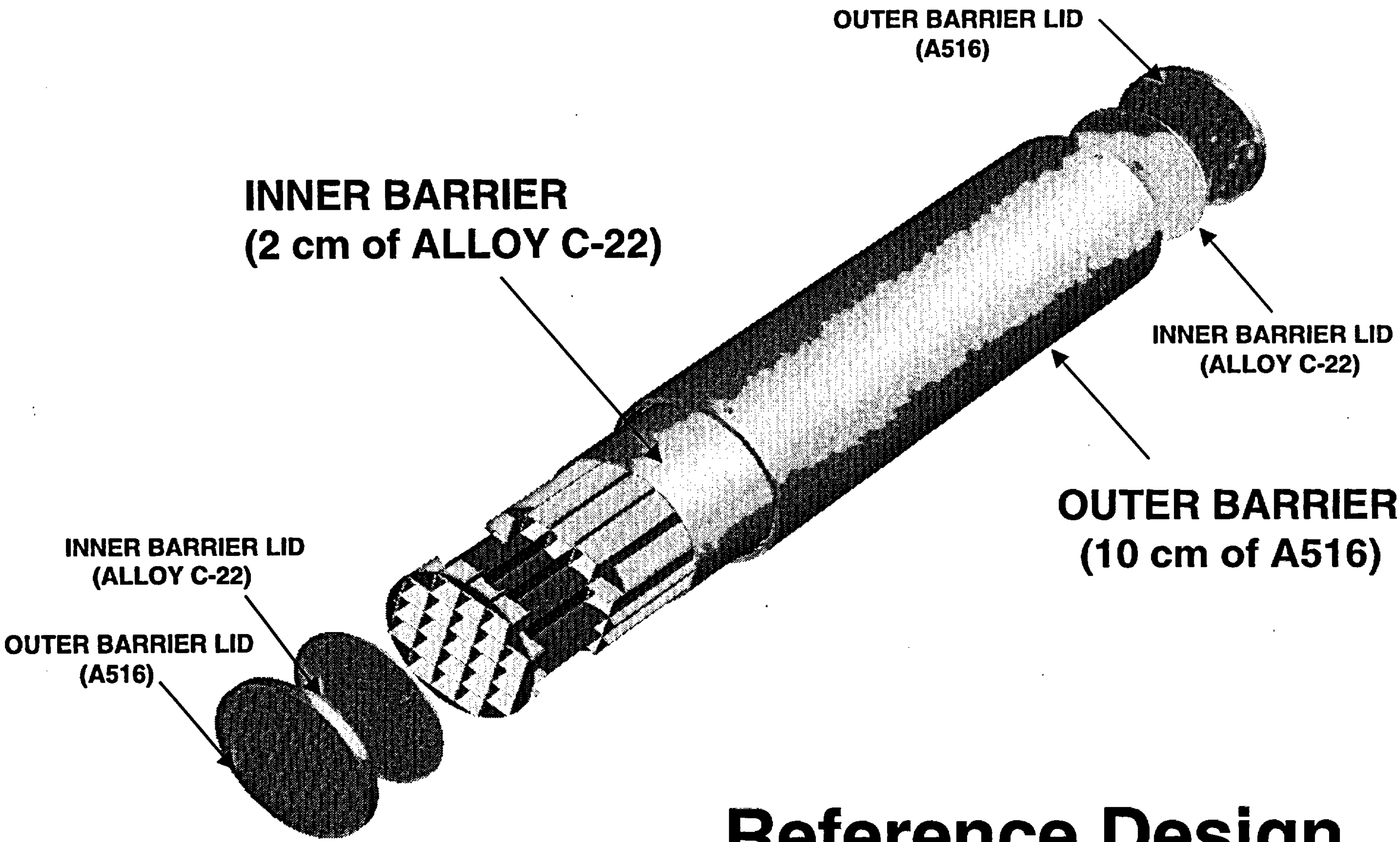
Presented by:
Jerry A. McNeish, EBS Department Manager
Duke Engineering and Services
Las Vegas, Nevada

April 23-24, 1998

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

Outline

- Reference Design for Waste Package
- Waste Package Degradation Conceptual Model and Bases
  - Juvenile failure
  - Corrosion allowance material
  - Corrosion resistant material
- Sensitivity Analyses
- Summary



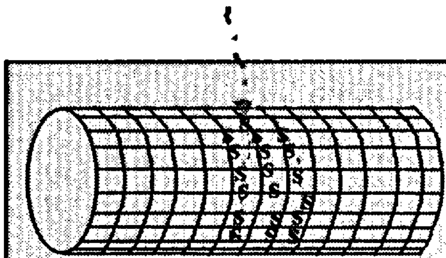
Reference Design for Waste Package

Waste Package Degradation Conceptual Model Key Concepts

Input

•Design
•Temperature
•Relative humidity
•Dripping
•Thresholds for corrosion initiation

Model



•Juvenile failure of WP
•CAM degradation
-general corr.
-localized corr.
•CRM degradation
-general corr.
-localized corr.

Output

•1st pit breach
•1st patch breach
•# of pits breach f(t)
•# of patches breach f(t)

Bases

•Short and long term corr. testing
•WP expert elicitation
•In-situ corr. testing
•Other literature data
•Field data

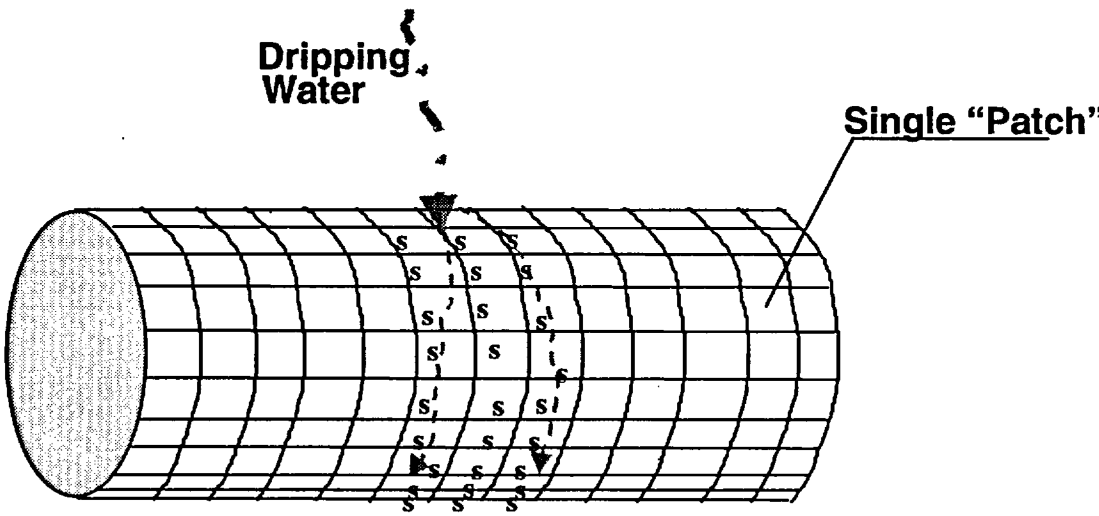
Juvenile Failure of Waste Package

- Early failure due to manufacturing defects,etc
- Analysis of weld failure - 10^{-5} probability of failure for a double-walled container (Massari, 1997)
- Canadian analyses indicate ~10^{-3} probability of early failure
- Base case failure distribution: 10^{-5} to 10^{-3} loguniform
  - deterministic case has 1 failure with 1 patch
- Failures only in dripping zones

Waste Package Degradation Conceptual Model

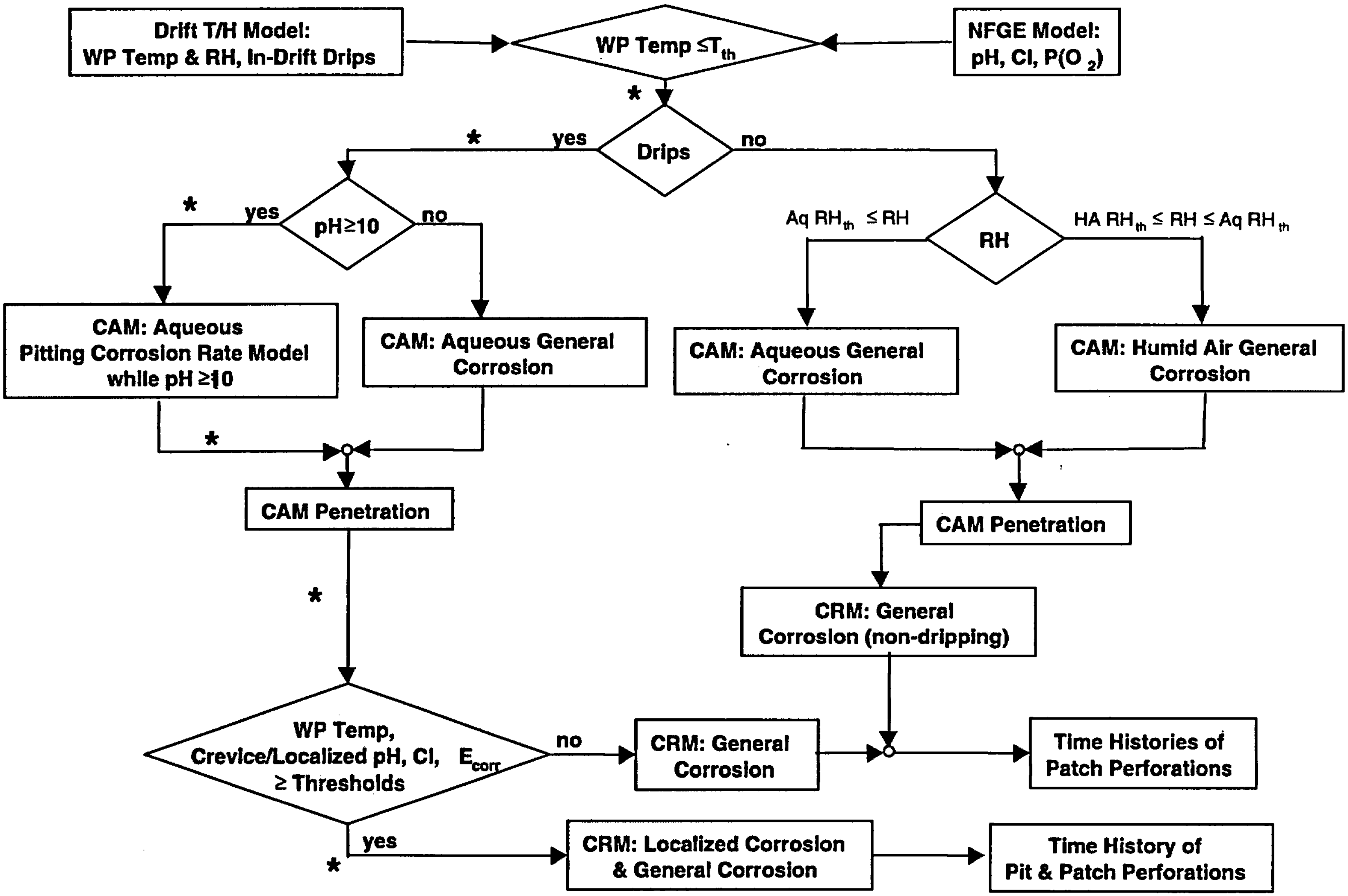
Inputs:

- T, RH, fraction of packages wet from drift-scale T/H abstraction and seepage model
- pH of dripping water from NFGE abstraction
- patches are 310 cm^2



s - Patches with drips;
Potential salt deposits;
CRM localized corrosion

Logic Diagram for the Base-Case TSPA-VA Waste Package Degradation Model



*** = fastest degradation pathway**

MCNEISH.PPT.125.NRC/3-17/19-9

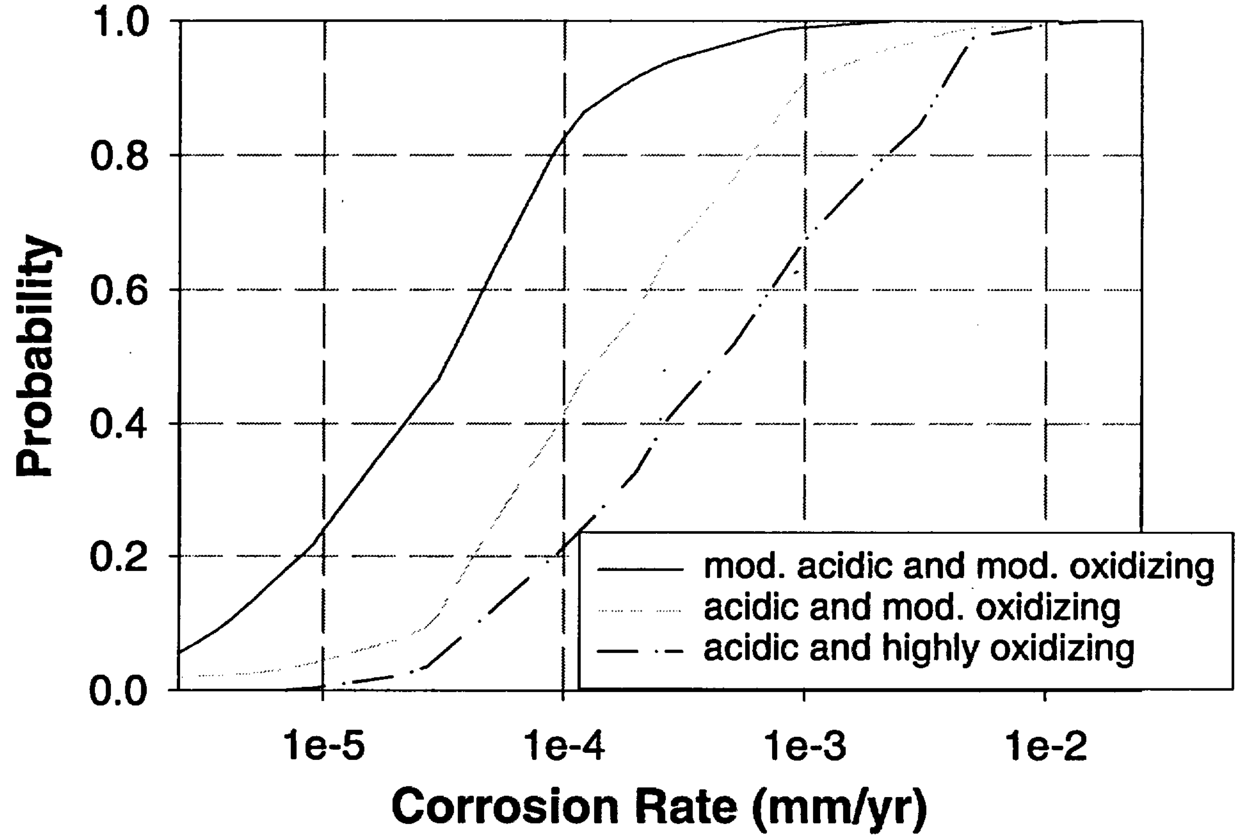
CAM Degradation Summary

- Details provided to NWTRB in October, 1997
- Humid air general corrosion as f(time, Temp, RH)
  - Humid air localized corrosion uses pitting factor
- Aqueous general corrosion as f(time,temp)
  - pH <= 10: localized corrosion uses pitting factor
  - pH >10: high aspect ratio pitting corrosion

CRM Corrosion Models

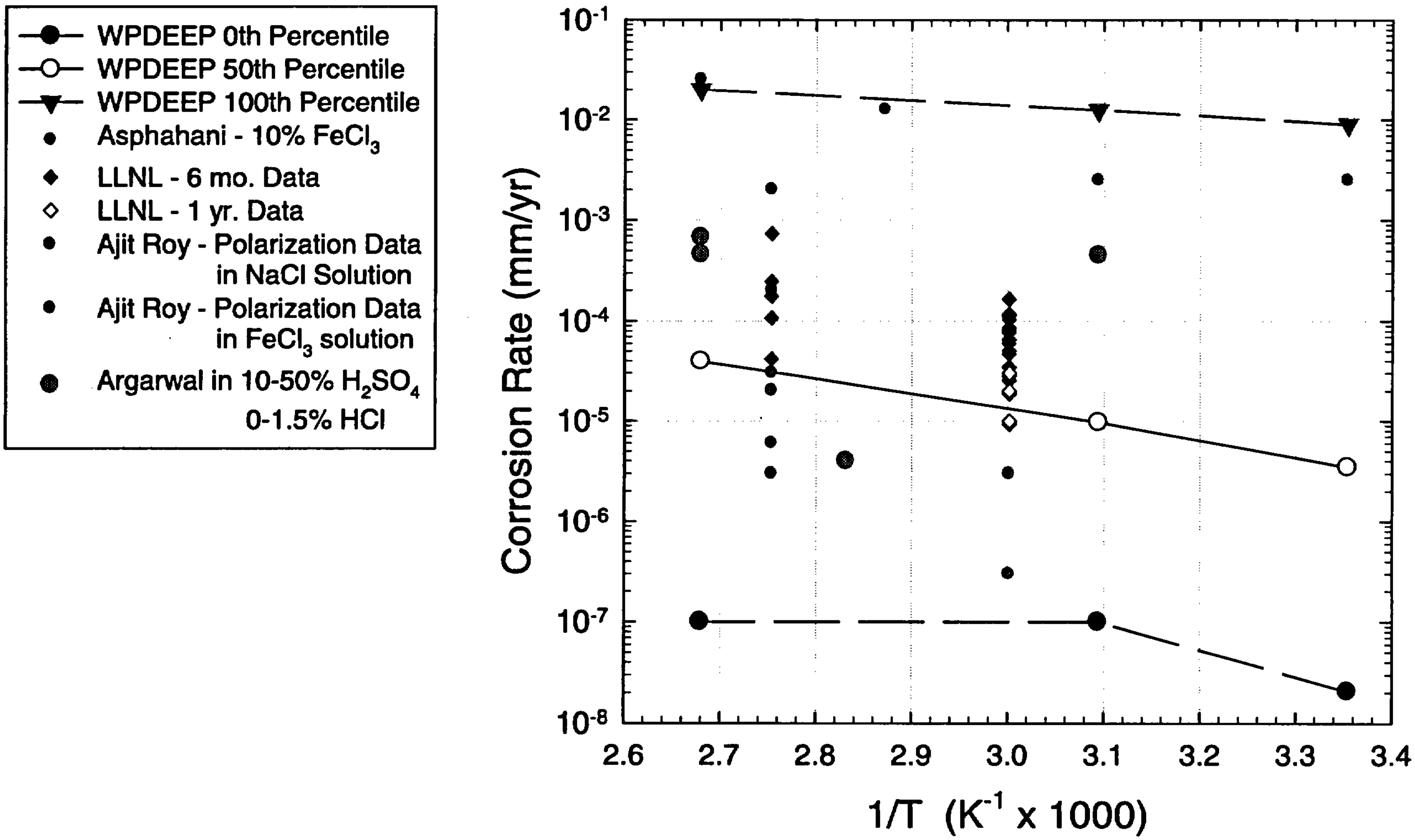
- General Corrosion (from WPDEE)
  - non-dripping conditions
  - dripping conditions
- Localized Corrosion
  - based on 6-month data from Long-term Corrosion Test Facility, short term data from LLNL, and literature data

CRM General Corrosion Rates for Alternative Environments at 100^0 C



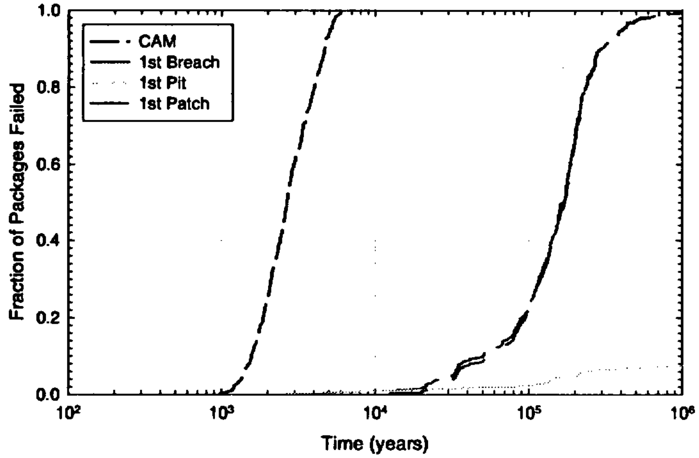
CRM General Corrosion Rate: Expert Elicitation and Data

C-22 General Corrosion Rate vs. 1/T

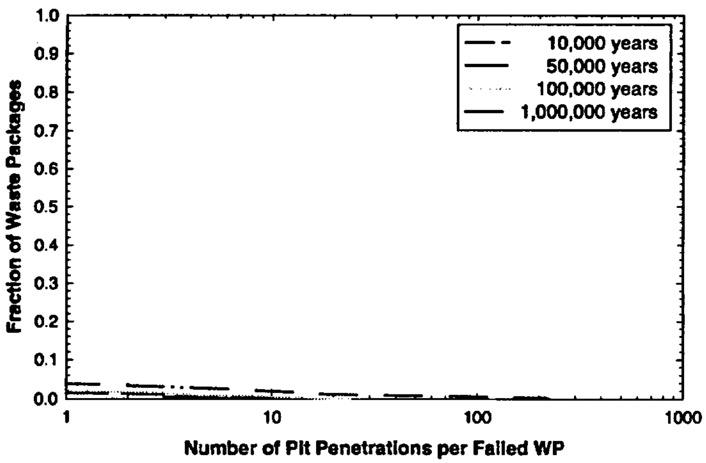


Base-Case WP Performance Analysis Results

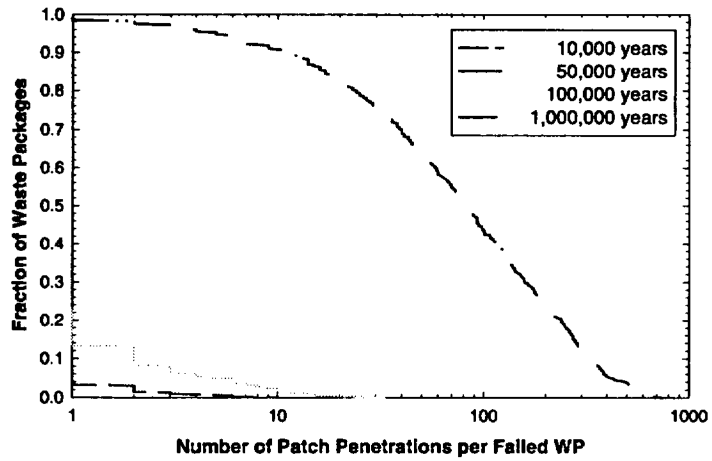
Waste Package Failure



Pit Penetration



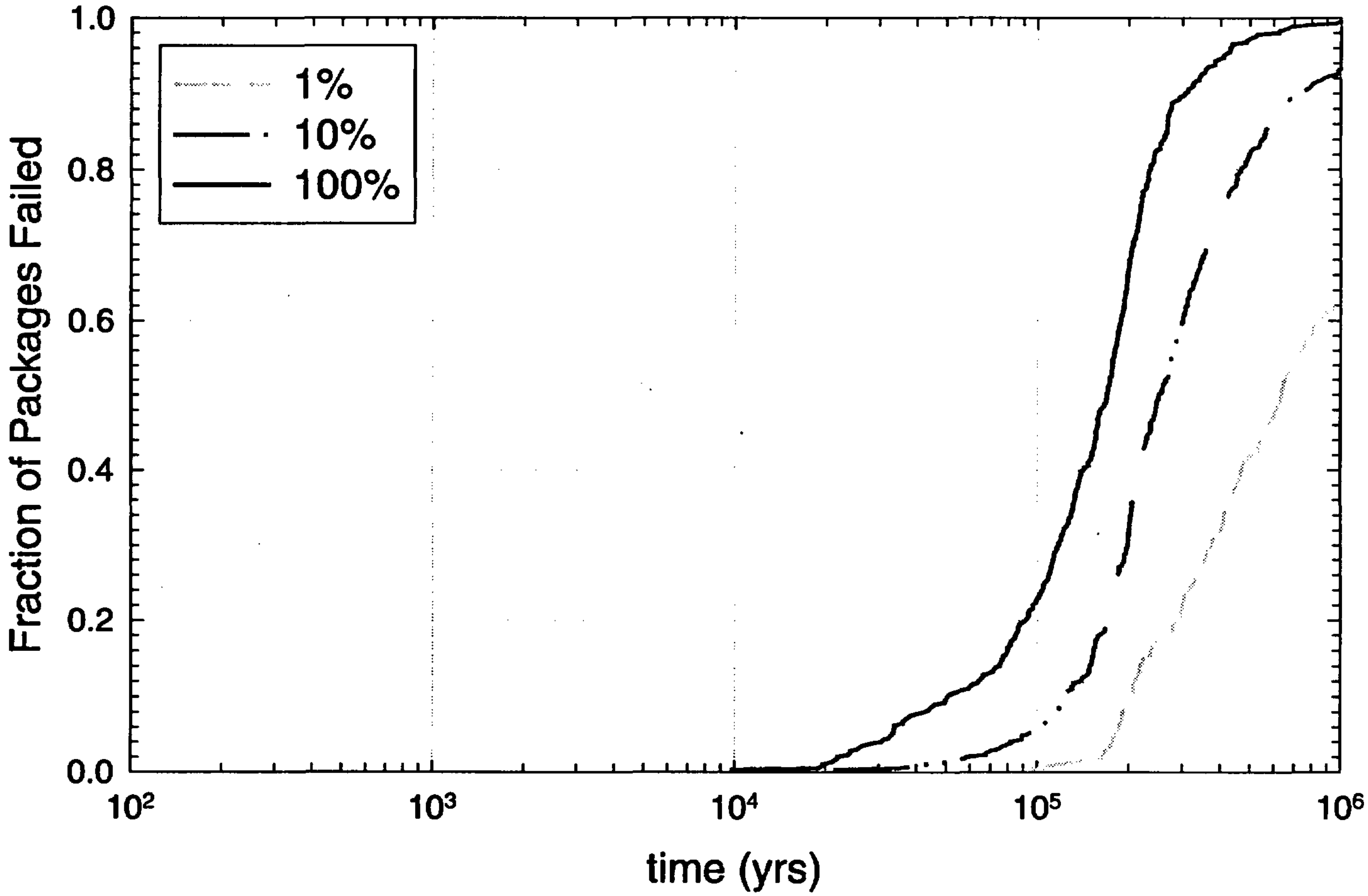
Patch Penetration



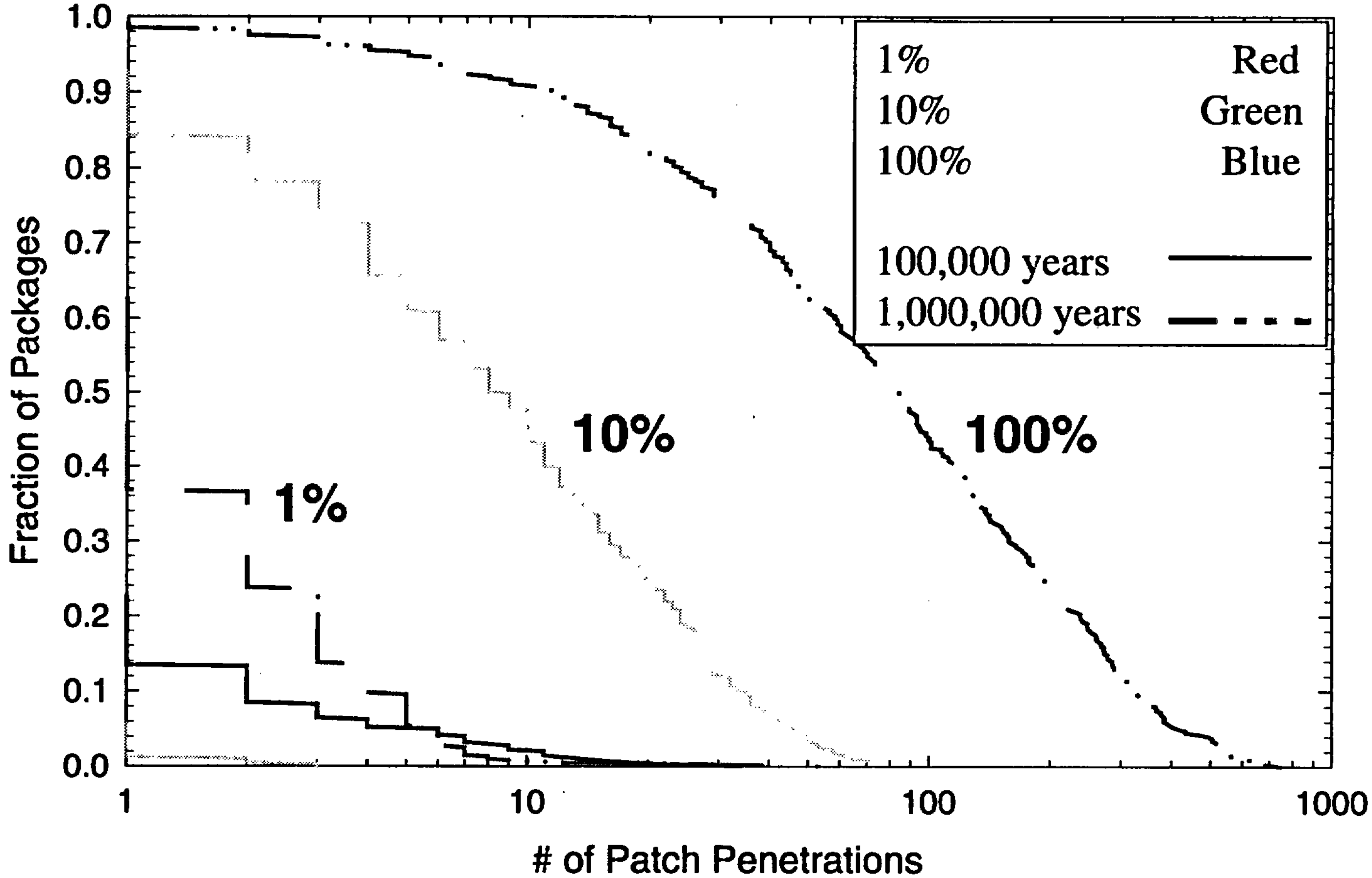
Waste Package Degradation Sensitivity Analyses

- Wetting conditions
  - % of WP wet
- Uncertainty/variability
- Juvenile failure
- Additional cases not completed:
  - Design options

Sensitivity of WP Failure to Waste Package Surface Fraction Wetted



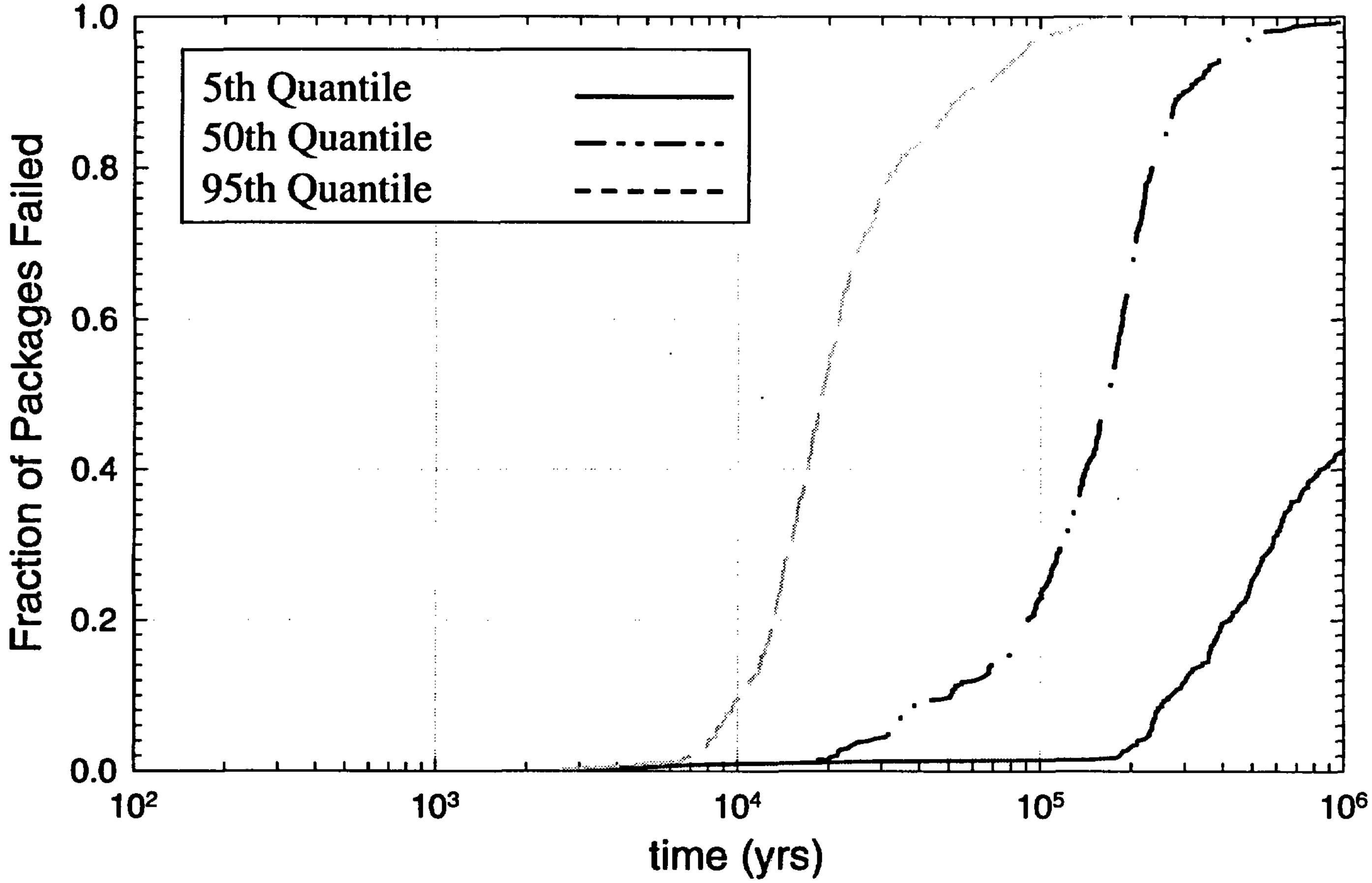
Sensitivity of Number Patch Penetrations to WP Surface Fraction Wetted



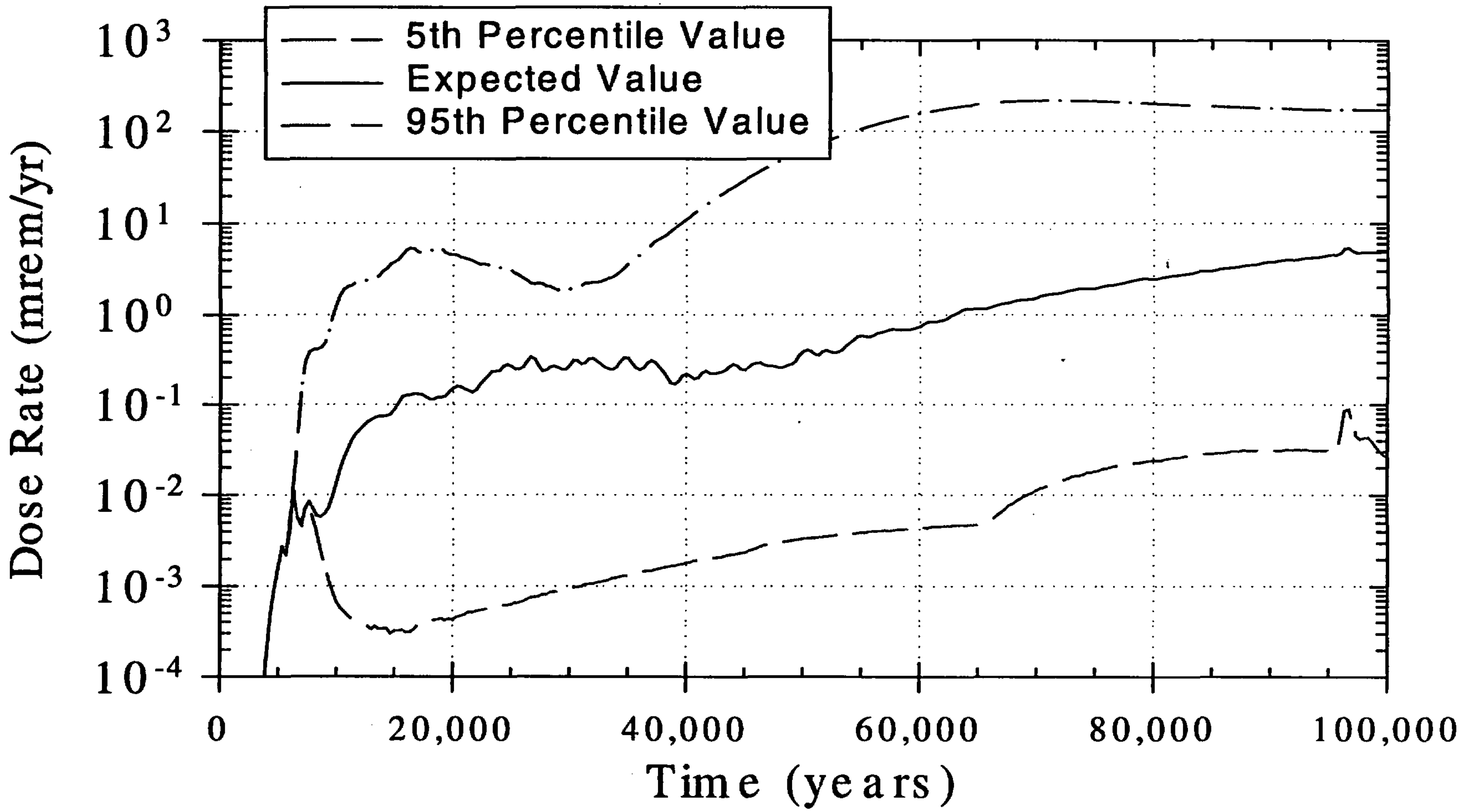
Variability and Uncertainty in Waste Package Degradation Model

- Variability in drift environment, waste packages will contribute to range of degradation
- Uncertainty in corrosion rates will contribute to range of degradation
- Evaluated this using split of the total variance for variability and uncertainty to cover possible range
- Model indicates most rapid failure has high variability, high percentile of uncertainty
- Model indicates best performance from low variability, low percentile of uncertainty

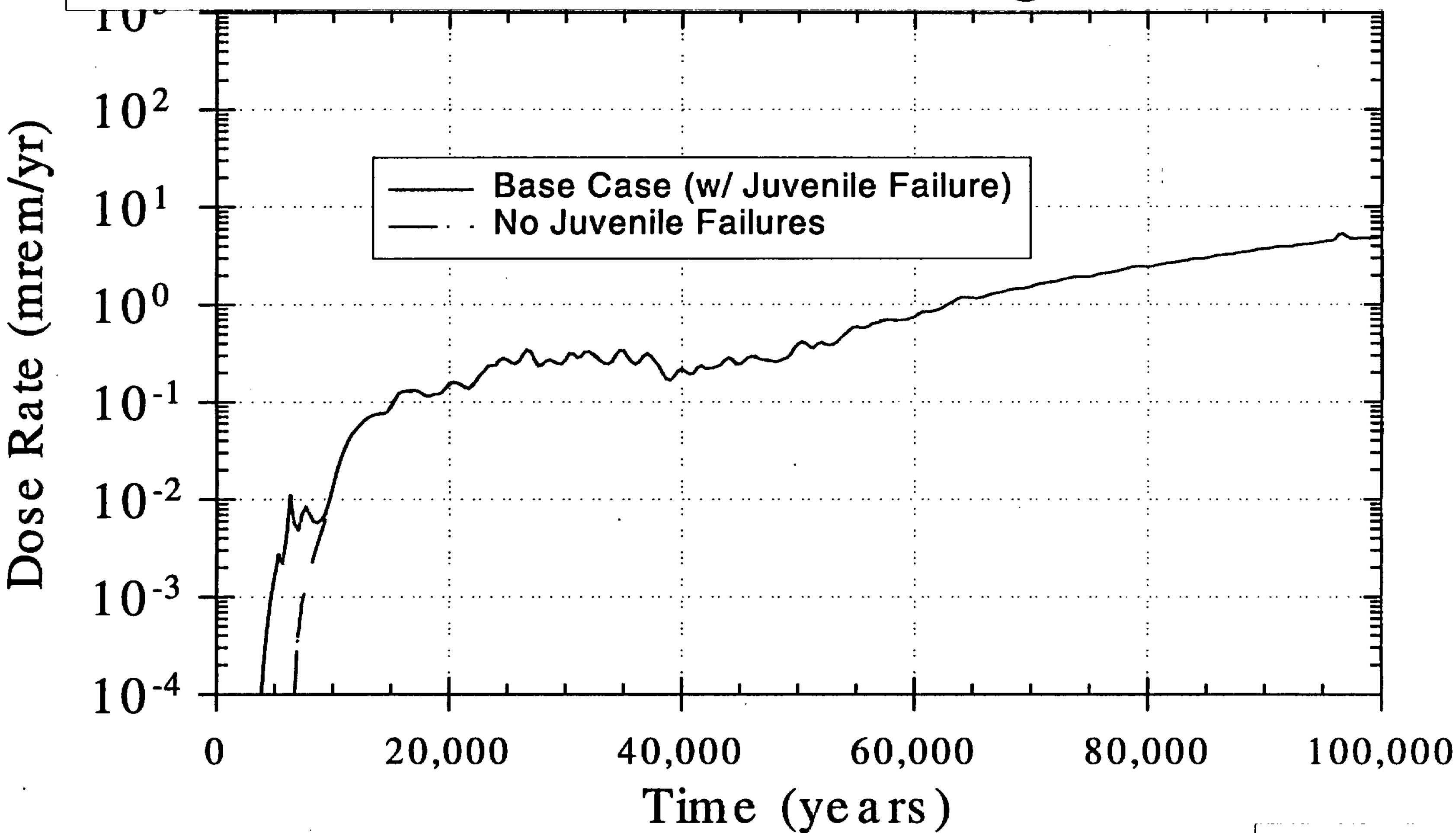
Sensitivity of WP failure to Uncertainty Percentile



Sensitivity of Dose to Waste Package Uncertainty Percentile



Sensitivity of Dose to Juvenile Failures of Waste Package



Summary/Conclusions

- Model includes juvenile failure of WP, CAM degradation, and CRM degradation
- Model supported by significant lab/field data as well as expert elicitation
- Primary factor affecting long-term waste package performance is dripping condition
- Factors not considered with potential negative performance implications are MIC, stress corrosion cracking, and structural failure of WP at late time

Summary/Conclusions
(continued)

- Key additional data requirements
  - Additional evaluation of dripping
  - Experimental data to substantiate/validate the WPDEE results, especially CRM corrosion rates, in the expected exposure conditions of the potential repository

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Studies

Evaluation of EBS Processes: Near field geochemical environment, Waste form degradation/mobilization, EBS transport

Presented to:
Nuclear Waste Technical Review Board
Performance Assessment Panel
Albuquerque, New Mexico

Presented by:
Jerry A. McNeish, EBS Department Manager
Duke Engineering and Services
Las Vegas, Nevada

April 23-24, 1998

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

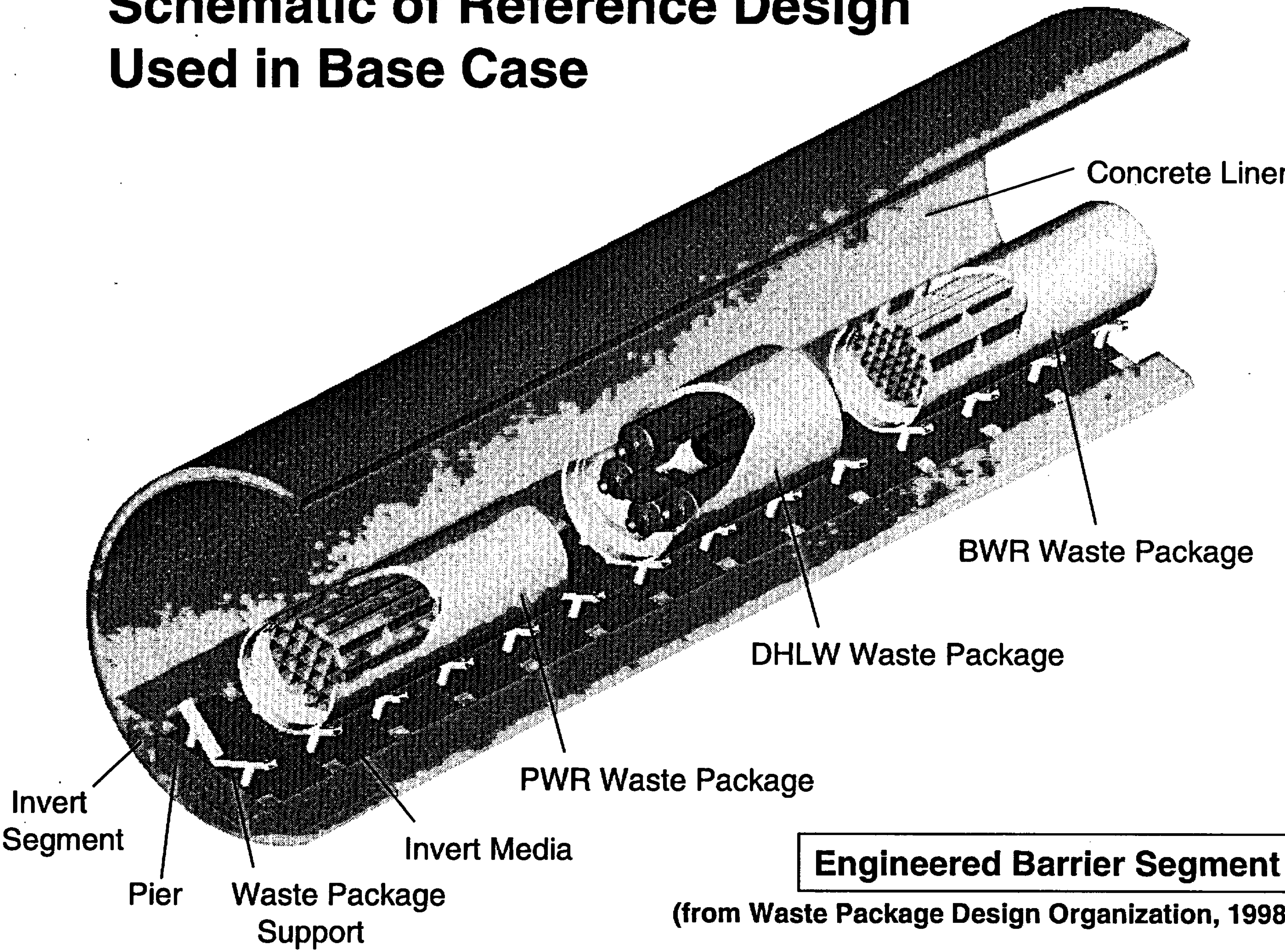
Outline

- Near Field Geochemical Environment
  - Conceptual Models
  - Bases for NFGE Models
  - Results from NFGE Models
- Waste Form Degradation
  - Conceptual Models
  - Bases for WF Degradation Models
  - Results from WF Degradation Models

Outline
(Continued)

- Radionuclide Mobilization
  - Conceptual Models
  - Bases for WF Mobilization Models
  - Results from WF Mobilization Models
- Engineered Barrier System Transport
  - Conceptual Models
  - Bases for EBS Models
  - Results from EBS Models

Schematic of Reference Design Used in Base Case



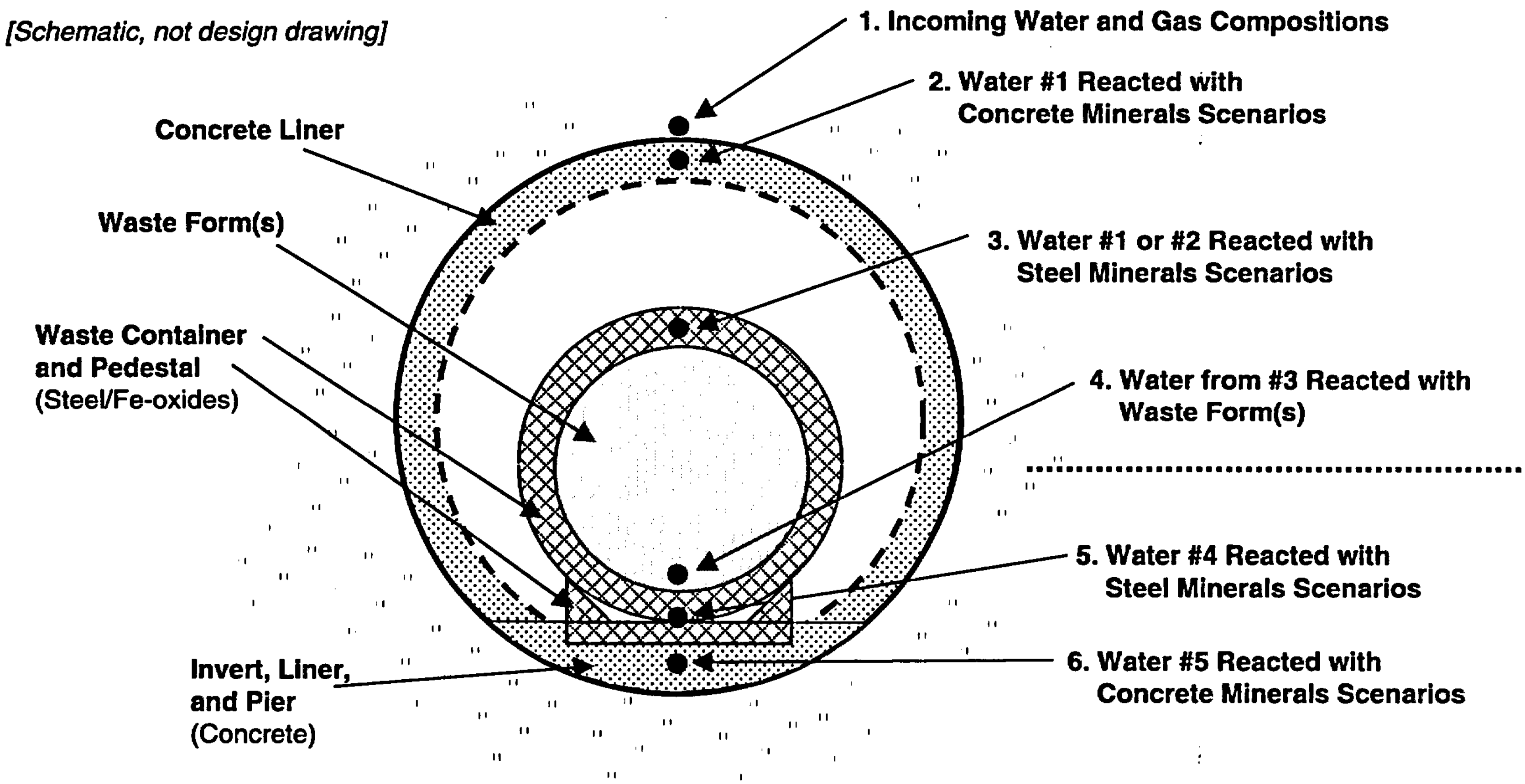
Engineered Barrier Segment

(from Waste Package Design Organization, 1998)

NFGE Conceptual Model

- Discretize the EBS to evaluate
- Scenarios defined based on thermal conditions
- Locations defined based on discrete locations within the EBS
- Evaluate gas and water compositions at the various locations within the EBS

TSPA-VA Base-Case Near-Field Geochemical Environment

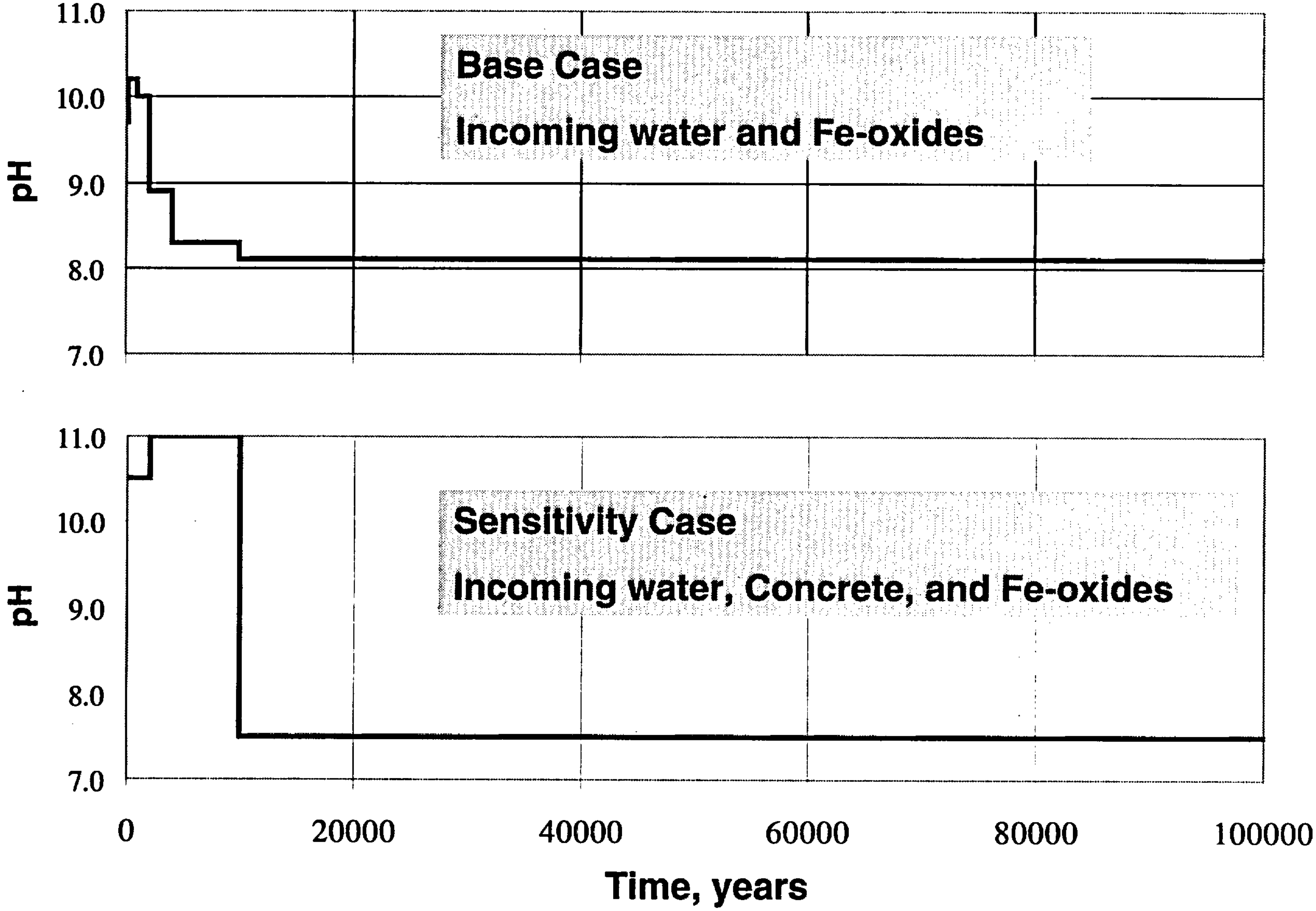


Schematic Representation of Materials Included for Base-Case NFGE and Locations along a Conceptual Pathway for Evaluation of Water Compositions [modified from M&O, 1998 B00000000-01717-2200-00200].

NFGE Abstraction Summary

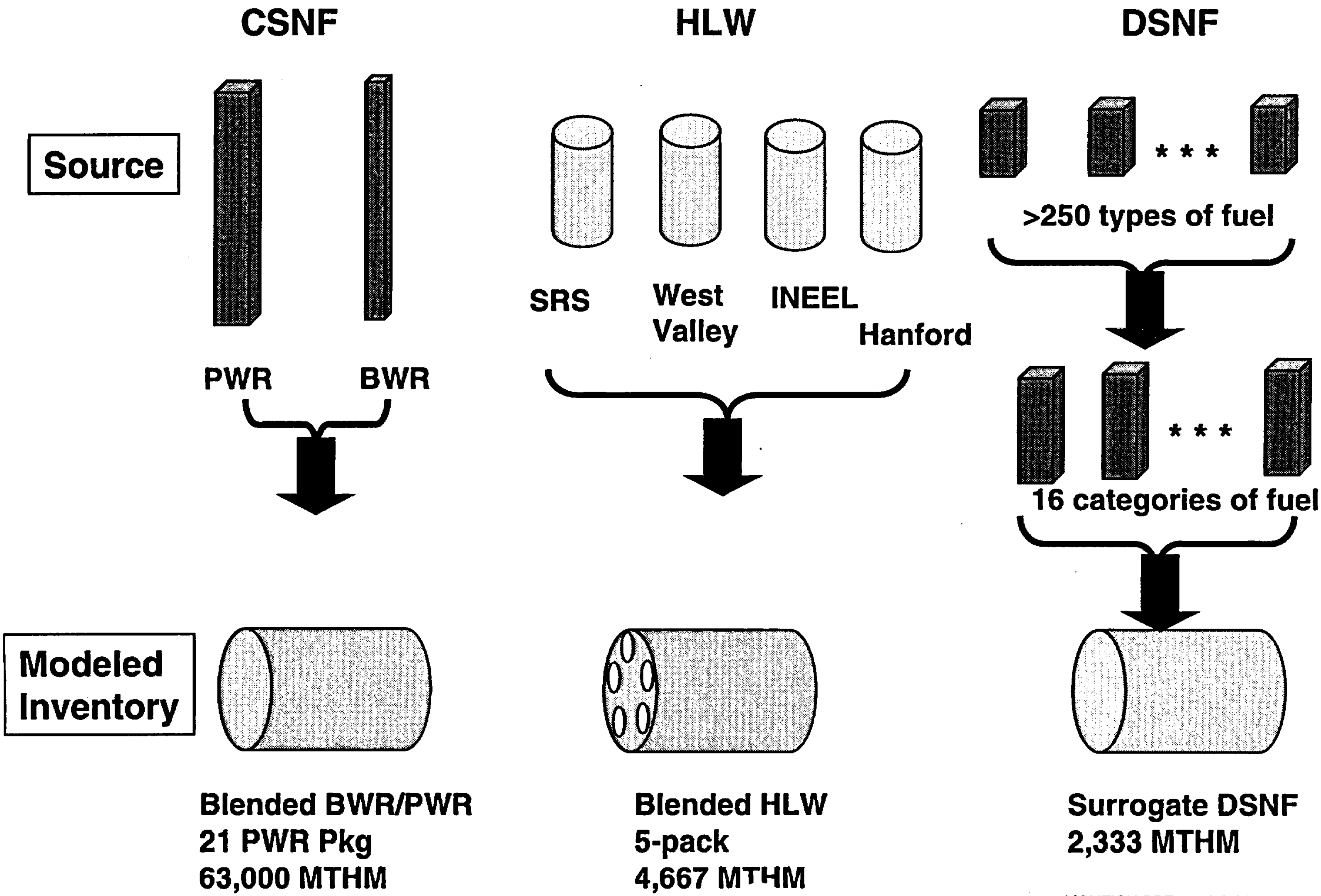
- Develop NFGE Gas and Water Compositions as f(t)
  - Input: gas flux & air-mass fraction from 2-D Mtn Scale TH results
  - Input: air composition (pO_2 and pCO_2) from pore-gas and single heater test data
- Calculate NFGE Water Composition as f(location, t)
  - include thermal effects on incoming water (boiling, pCO_2)
  - include in-drift reactions
  - include in-package reactions with spent fuel
- Output: pH, $\sum CO_3^{-2}$, and I (ionic strength) as f(t)

pH of water flowing into waste package



[Revised 20-Apr-98, NFGErev01reslt.ppt]

Waste Form Inventory Abstraction



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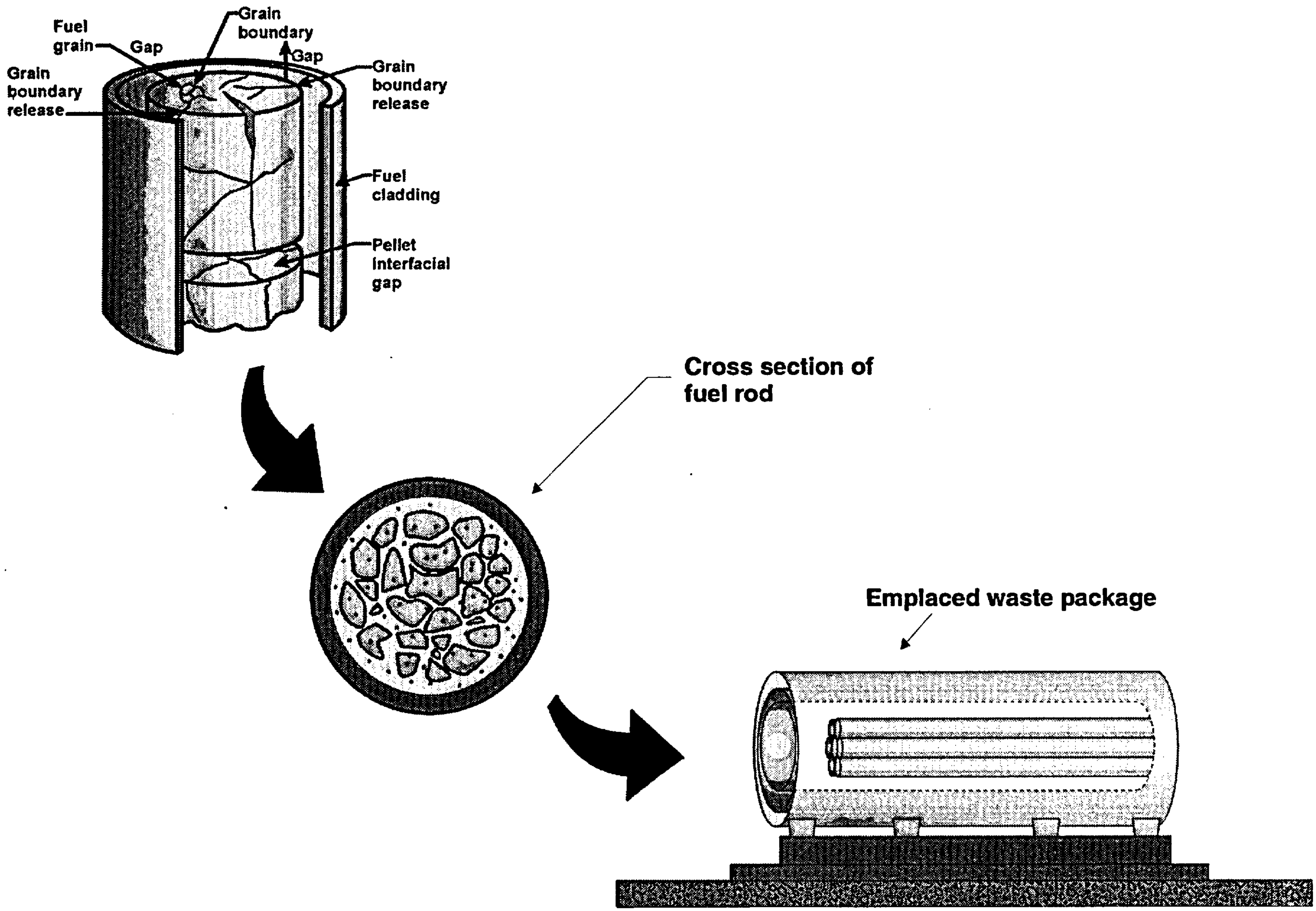
Waste Form Degradation/Radionuclide Mobilization Conceptual Model

- Assume waste forms exposed to the drift environment upon failure of the waste package and cladding.
- Assume water films adsorbed on porous alteration product layers provide aqueous conditions
- Waste form degradation is represented by an "Intrinsic Dissolution Rate" equation
- Radionuclides are considered potentially available for mobilization congruent with this dissolution

Waste Form Degradation/Radionuclide Mobilization Conceptual Model
(Continued)

- Mobilization of highly soluble radionuclides at this dissolution rate, into either diffusive or advective EBS transport
- Most radionuclides are mobilized at aqueous solubility limits
- A preliminary representation of aqueous concentrations limited by secondary phase formation has been prepared, but is not in the initial base-case

Waste Form Schematic

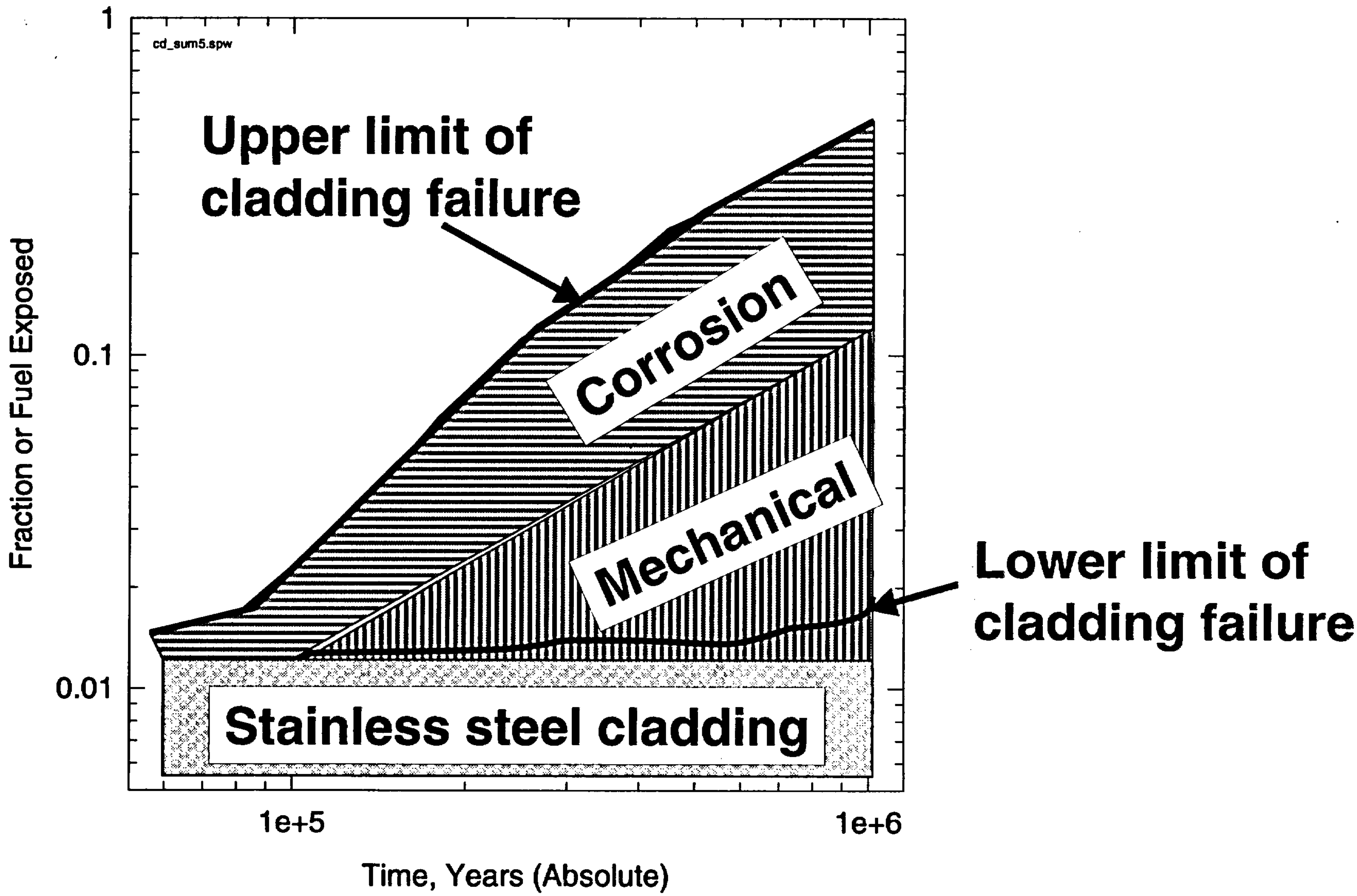


MCNEISH.PPT.125.NRC/3-17/19-9(

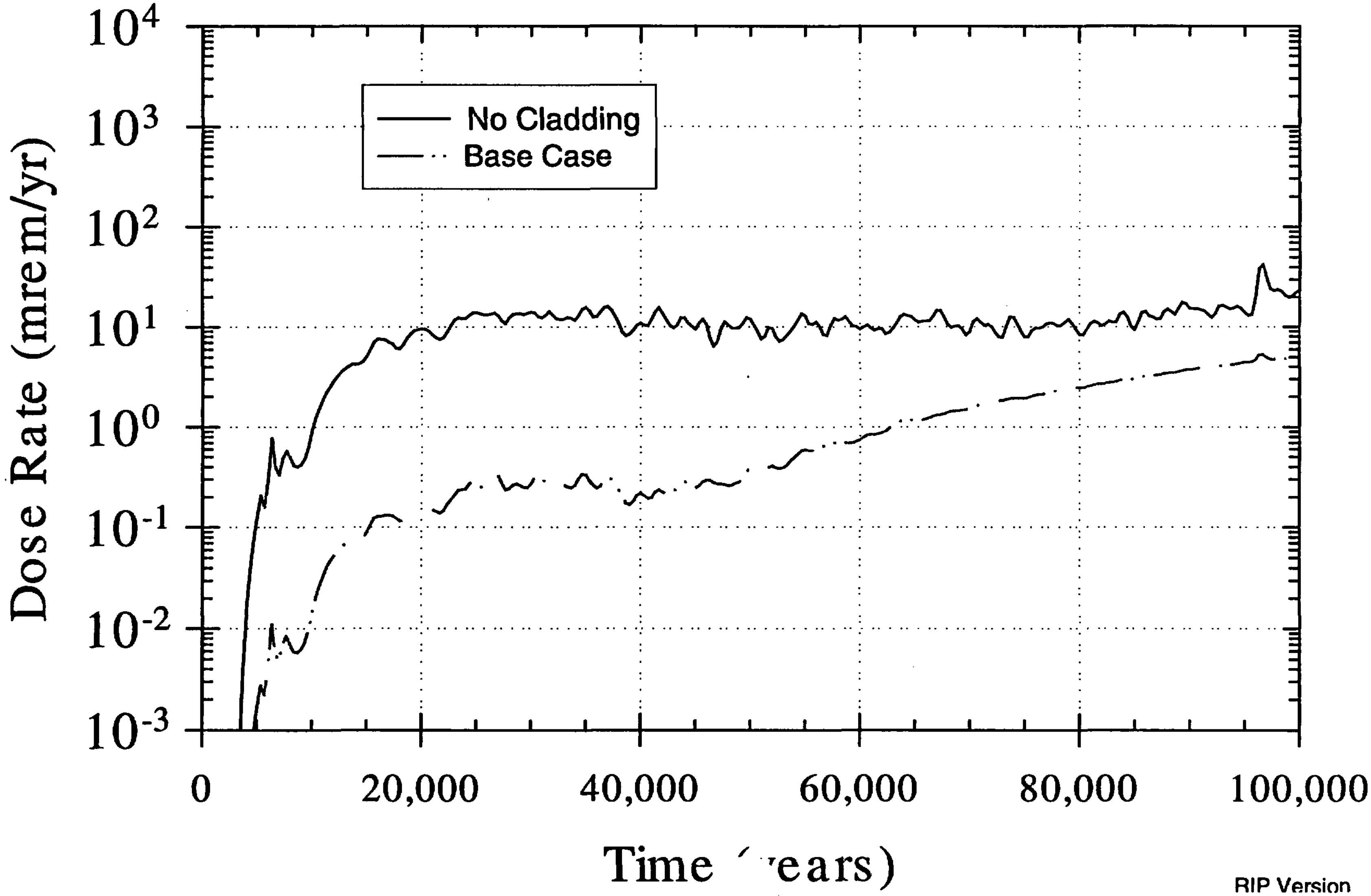
Failure Modes in Cladding Model

- Juvenile cladding failure
  - early time failure of cladding
- Stainless Steel cladding failure
  - assumed to fail at time of waste package failure
- Creep (strain) cladding failure
- Mechanical failure
  - due to rod breakage from rockfall
- Corrosion of cladding
  - corrosion model similar to C-22 corrosion

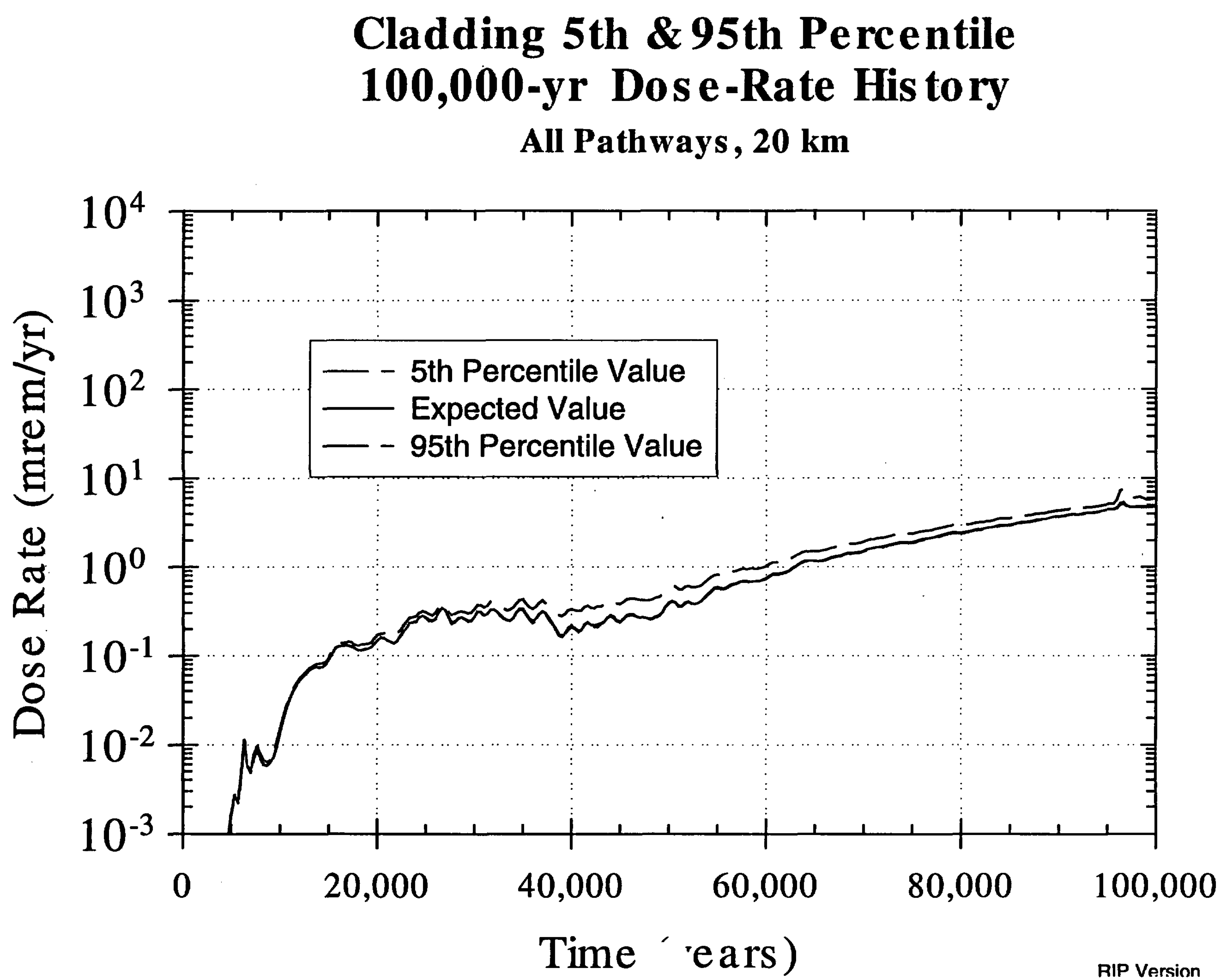
Cladding Degradation



Base Case vs No Cladding
100,000-yr Expected-Value Dose-Rate History
All Pathways, 20 km

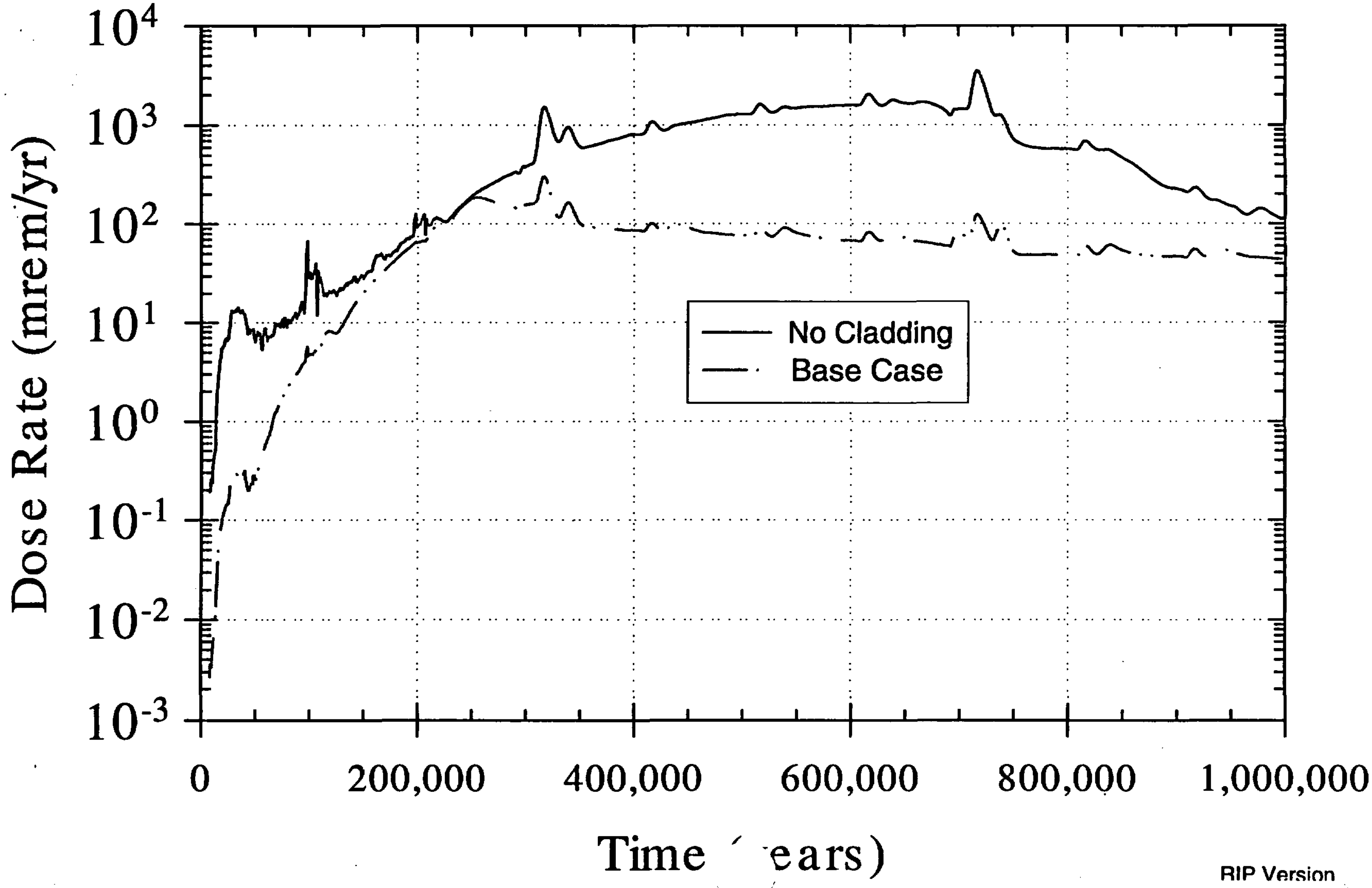


RIP Version



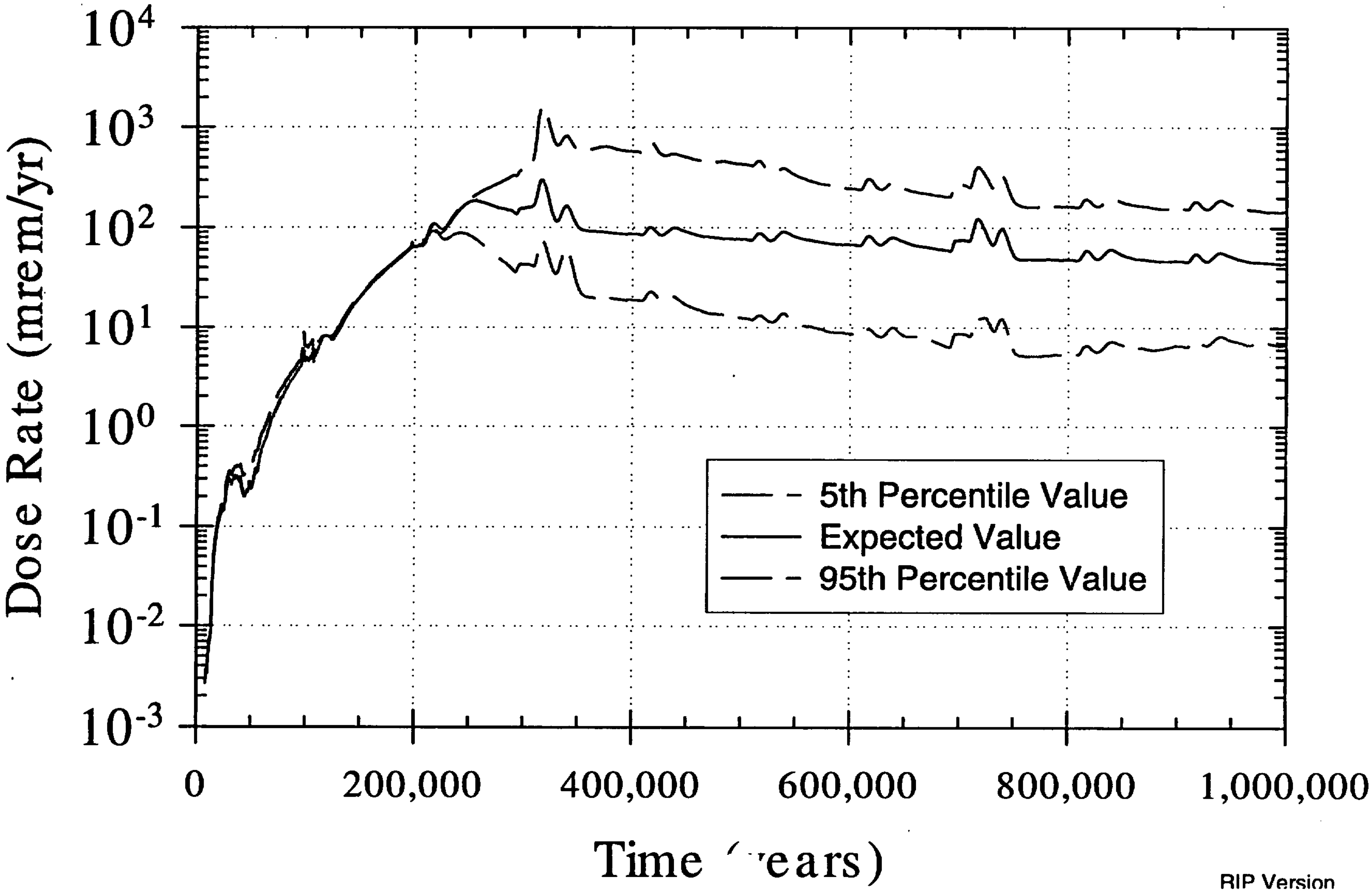
Cladding 5th & 95th Percentile
100,000-yr Dose-Rate History
All Pathways, 20 km
5th Percentile Value
Expected Value
95th Percentile Value
Dose Rate (mrem/yr)
10^4
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
0
20,000
40,000
60,000
80,000
100,000
Time (years)
RIP Version

Base Case vs. No Cladding
1,000,000-yr Expected-Value Dose-Rate History
All Pathways, 20 km



RIP Version

Cladding 5th & 95th Percentile
1,000,000-yr Dose-Rate History
All Pathways, 20 km

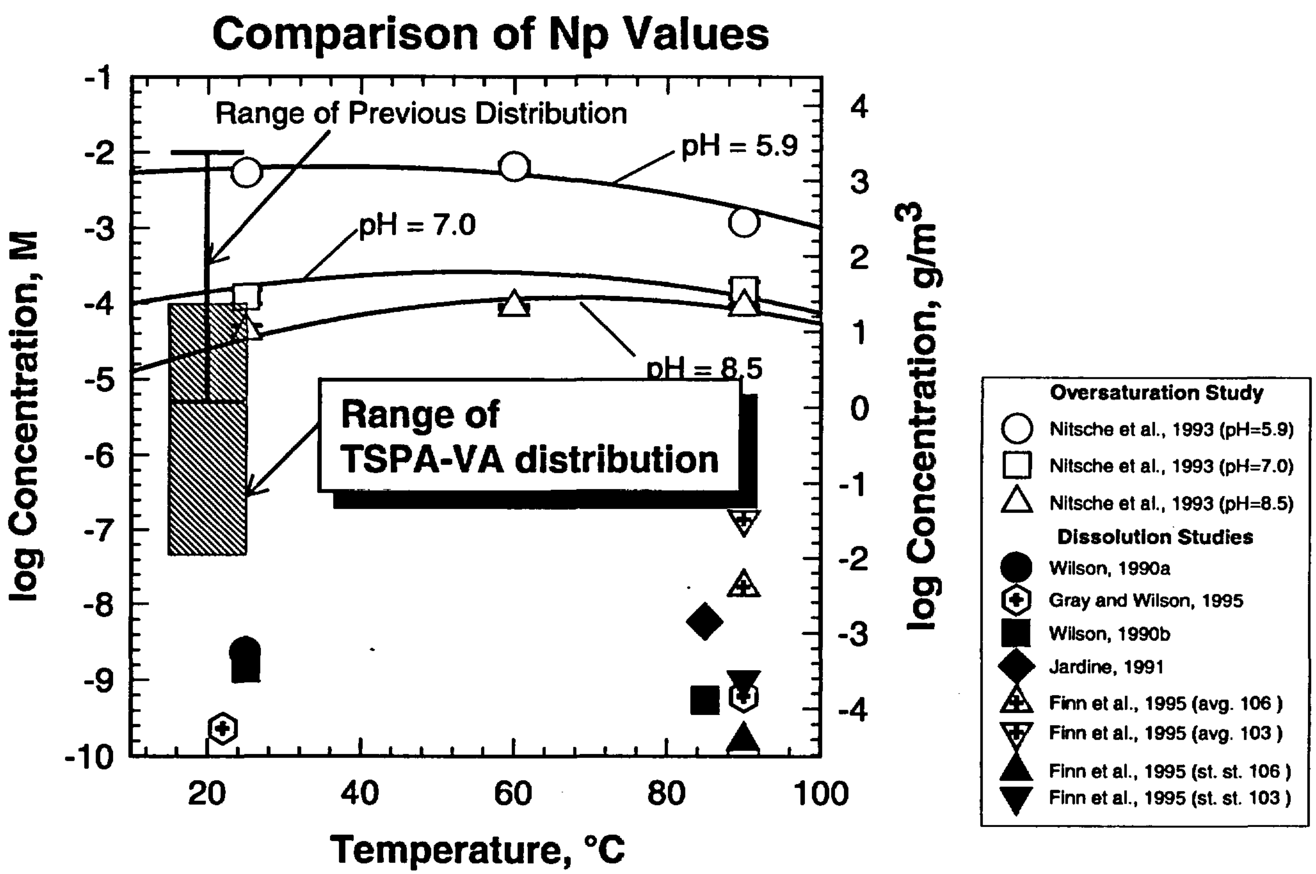


RIP Version

Radionuclide Solubilities

- Most radionuclides are released into the EBS transport process at their solubility limit
- Solubilities are sampled over a range with a minimum, maximum, average and probability distribution function
- In the current Base Case, solubilities (except Np) are the same as used in TSPA-95.
- After review, Np solubility has been reduced from TSPA-95 values by a factor of 100 (M&O, 1998)

Range of Solubility-Limited Np Concentrations



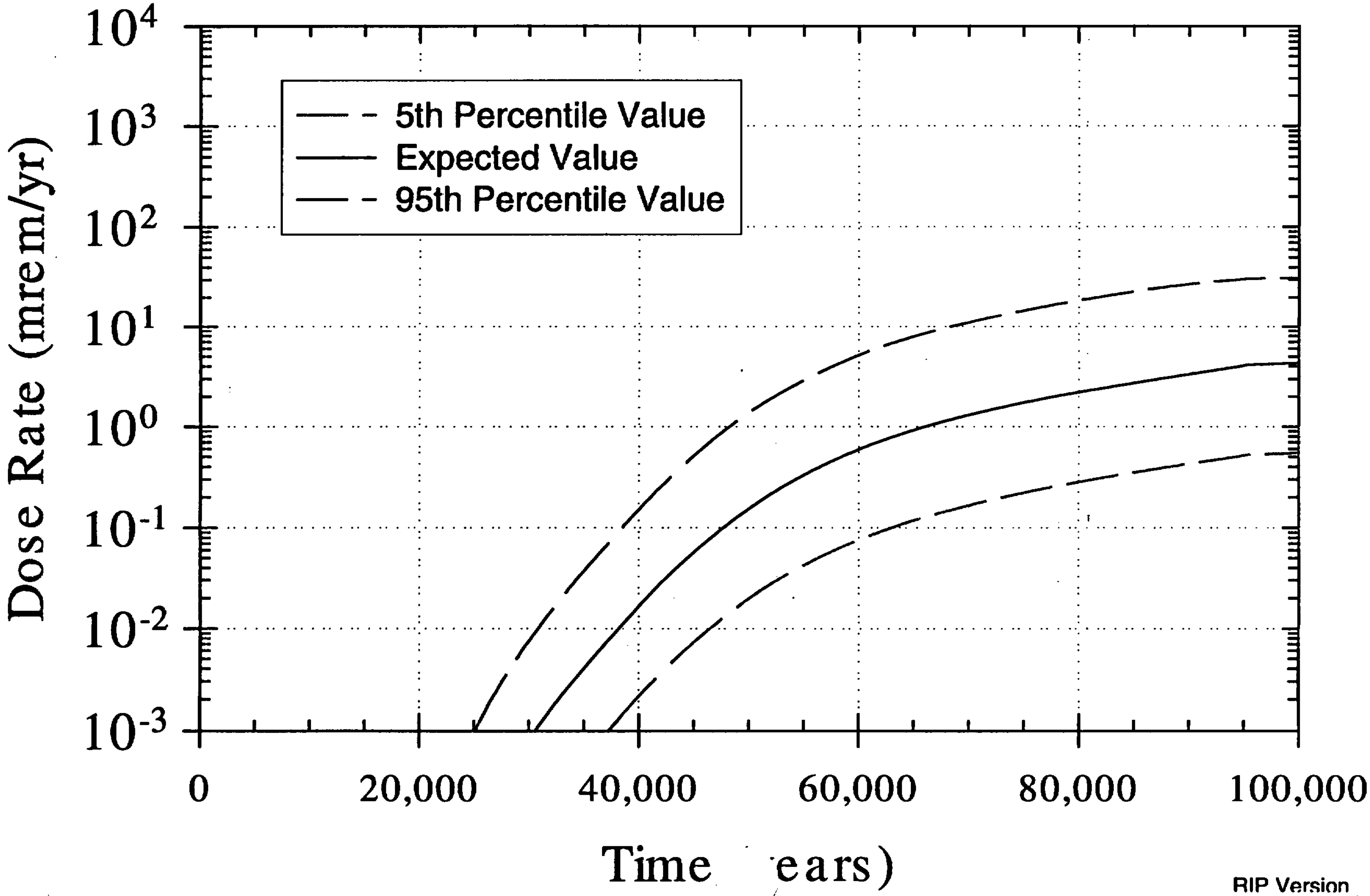
(from M&O, 1998)

Note: Np solubility 100 times less than TSPA-95

Summary of Change for Neptunium

- **Nitsche et al. Studies Used Concentrated Solutions from Np-salts to Approach from Oversaturation**
- **Thermochemical Data Suggest that Phases Formed in Studies Represent Metastable Solids**
- **Synthesized Results of Dissolution Studies**
  - **Does spent fuel in J-13-like fluids (starting with zero Np) reach such high values at steady state?**
    - » **flow-through tests**
    - » **drip tests**
    - » **batch studies**
  - **All Measured Np Concentrations Lower Than Needed to Saturate Phases in Nitsche et al. Studies**
    - » ***highest* time-averaged value is 1/37 of the *lowest* elicited value and steady-state values are even lower**
- **Metastable Phases not Expected to Apply, Stable Phases like NpO_2 Should Keep Np Below about 1/100 of the Elicited Range**

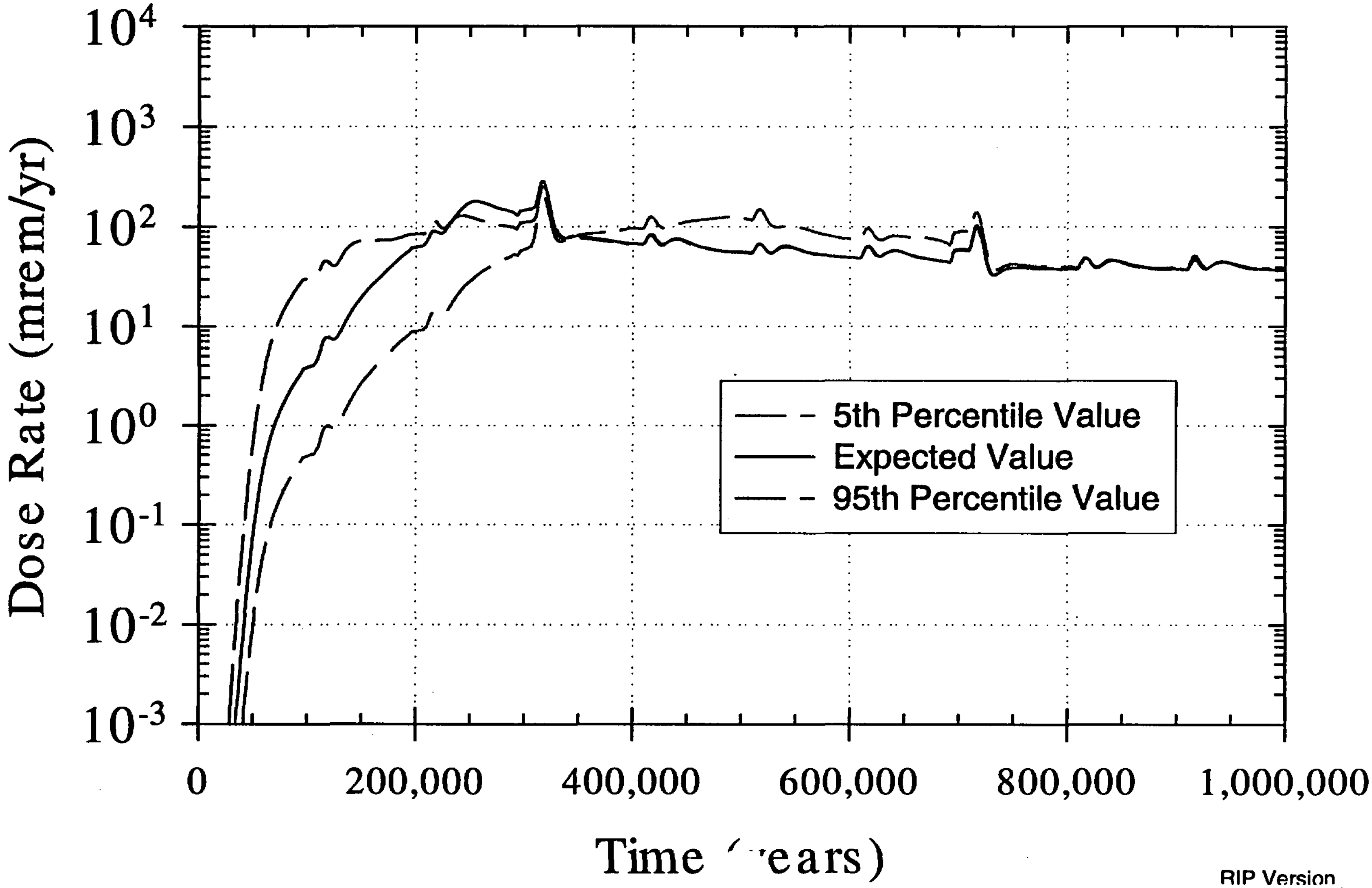
Np Solubility 5th & 95th Percentile
100,000-yr Dose-Rate History
All Pathways, 20 km



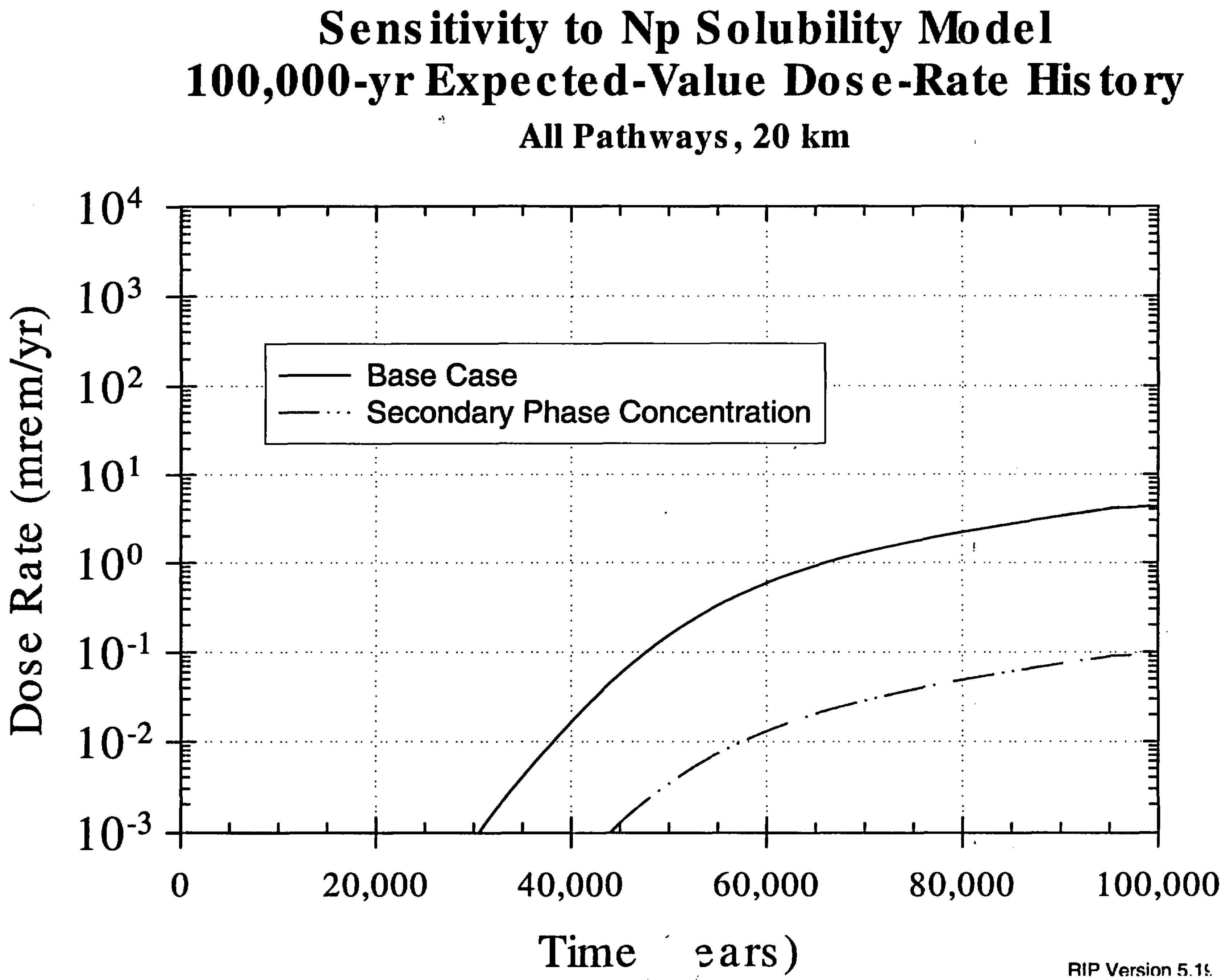
RIP Version

Np Solubility 5th & 95th Percentile
1,000,000-yr Dose-Rate History

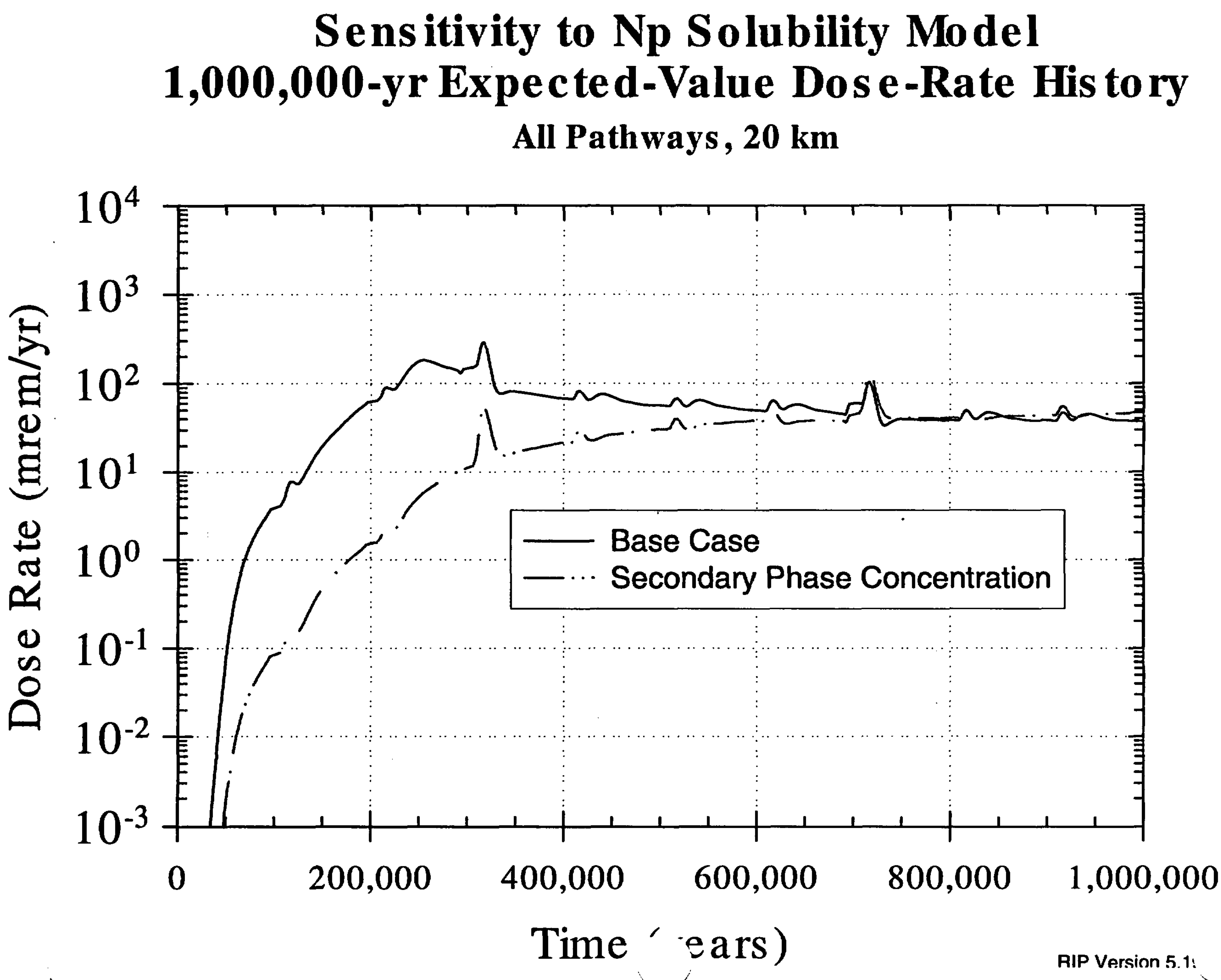
All Pathways, 20 km



RIP Version



RIP Version 5.1

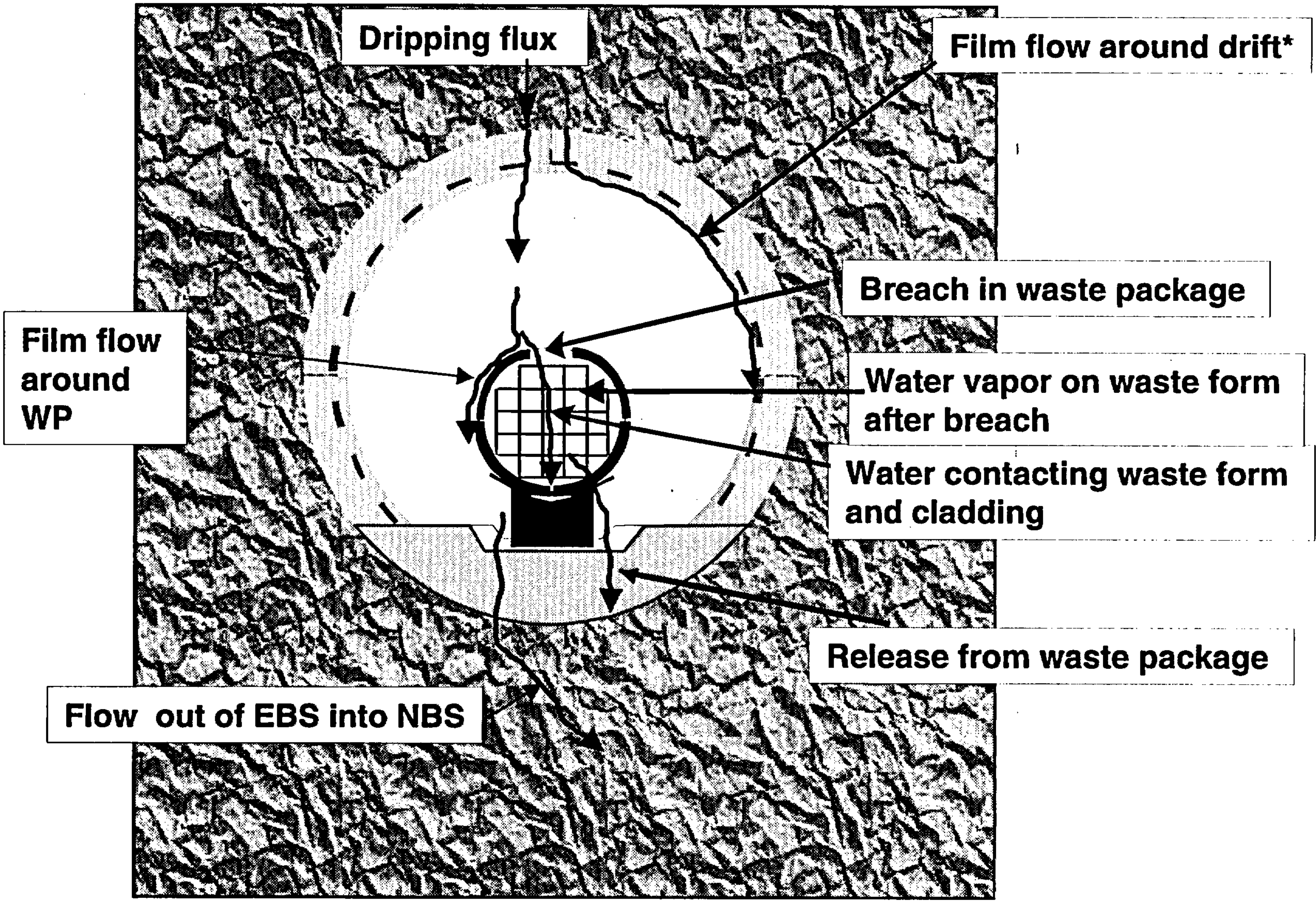


Sensitivity to Np Solubility Model
1,000,000-yr Expected-Value Dose-Rate History
All Pathways, 20 km
Dose Rate (mrem/yr)
10^4
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
0
200,000
400,000
600,000
800,000
1,000,000
Base Case
Secondary Phase Concentration
RIP Version 5.1

Colloidal Plutonium Transport - Base Case

- May increase release from waste package and decrease travel time in near field and far field
- Significance depends on stability and reversibility of RN attachment
- Four colloid types considered in TSPA-VA: clay, iron oxide, "spent-fuel waste-form" and "glass waste-form"
- Reversible sorption considered in TSPA-VA base case with ratio of amount mobilized on colloid to amount dissolved ($= K_c$) ranging from 10^{-5} to 10 based on laboratory data

Conceptual model of all potential water flow pathways through the EBS



*Not in base case

Engineered Barrier System Transport

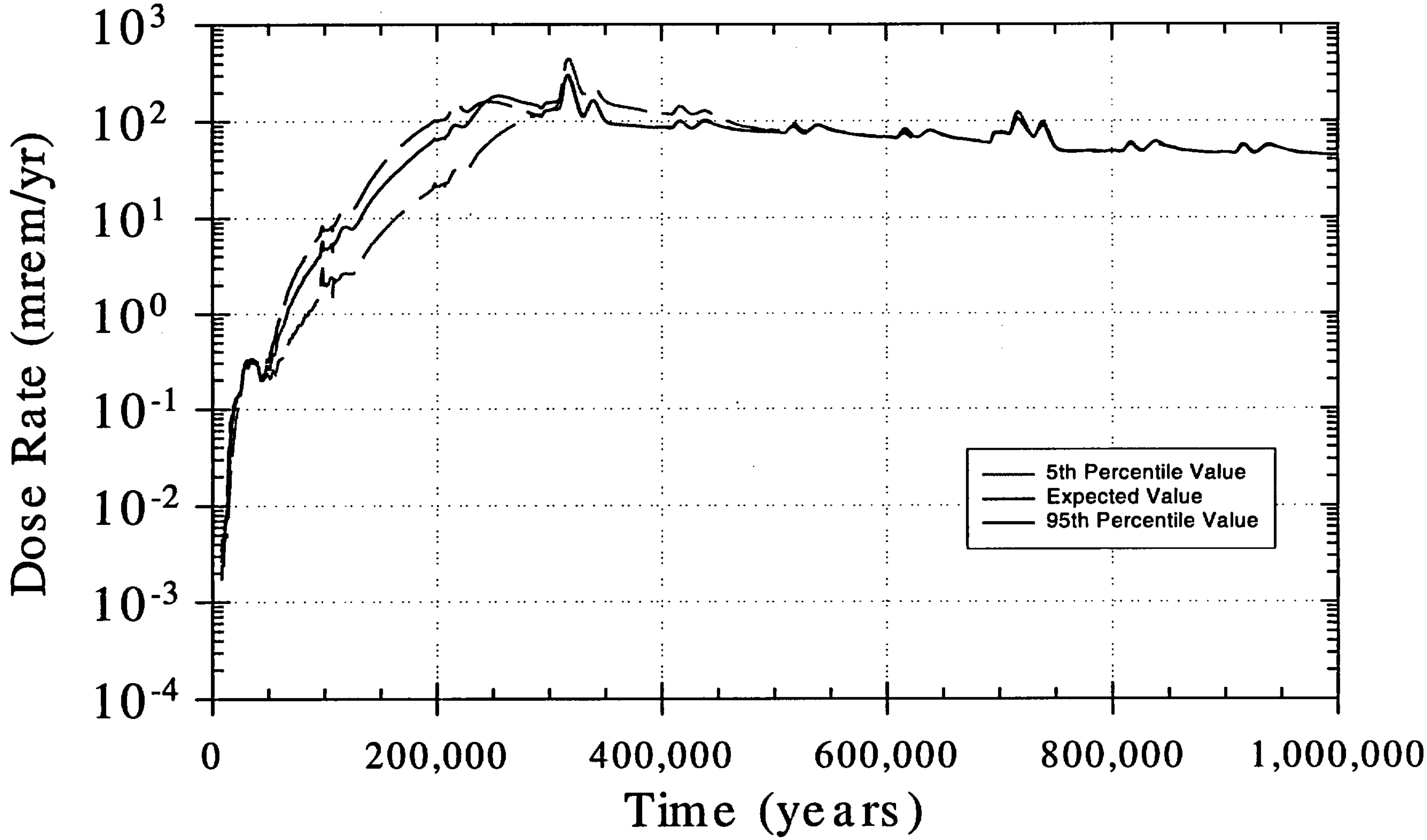
EBS release occurs when:

- WP is breached allowing air and/or water into can
- Clad is breached allowing air and/or water into WF
- Waste form degrades
- RN's are mobilized (dissolved and colloidal)
- RN's transport through EBS by advection and diffusion

Performance improves if:

- Protect WP from drips
- Clad remains substantially intact (protected from high heat and mechanical disruption)
- WF degradation very slow
- RN's less mobile (insoluble, little colloid mobilization)
- RN's transport slowly (advective and diffusive barriers, retardation)

Sensitivity of dose to seepage into waste package



Summary/Conclusions

- NFGE information included in TSPA-VA
- Improvements in waste form degradation and radionuclide mobilization models
- CSNF dissolution model has been extended to consider temperature, burnup, $\sum CO_3^{-2}$, pH and O_2
- HLW glass dissolution model has been updated
- Np elemental solubility updated
- Colloid mobilization has been added

Summary/Conclusions
(continued)

- Significant effect on EBS transport performance
  - Waste Package (and cladding) longevity
  - Np Solubility
  - Advection control
  - Colloid control (if necessary)
- Additional data requirements
  - Interaction of water with waste package and waste form
  - Nature of advective and diffusive flow paths in EBS
  - Geochemistry along flow paths in EBS

YUCCA MOUNTAIN PROJECT

Studies

UZ Transport, Colloids, SZ Flow and Transport, and Biosphere for TSPA-VA

Presented to:
NWTRB Panel on Performance Assessment
TSPA-VA
Albuquerque, New Mexico

Presented by:
S. David Sevougian, Total System Department Manager
CRWMS M&O, Performance Assessment Operations
Duke Engineering & Services, Las Vegas, NV

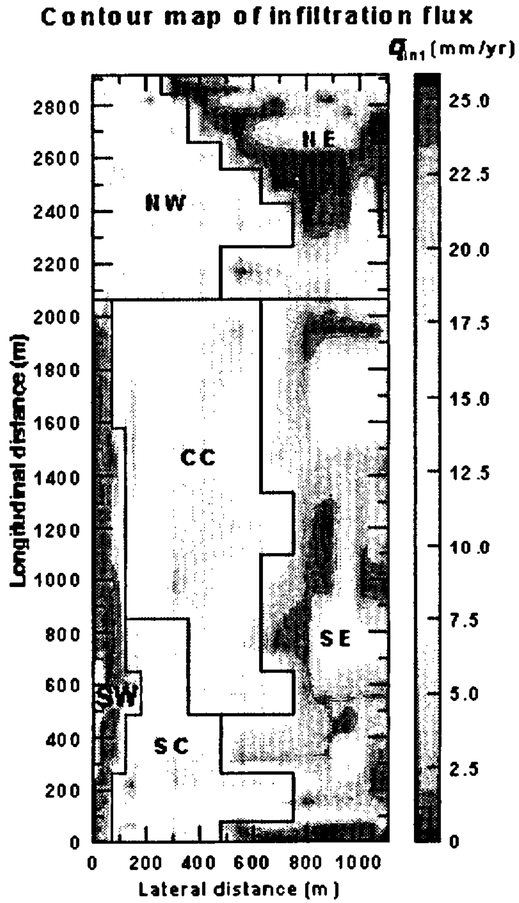
April 23, 1998

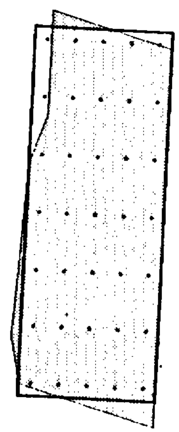
U.S. Department of Energy
Office of Civilian Radioactive
Waste Management

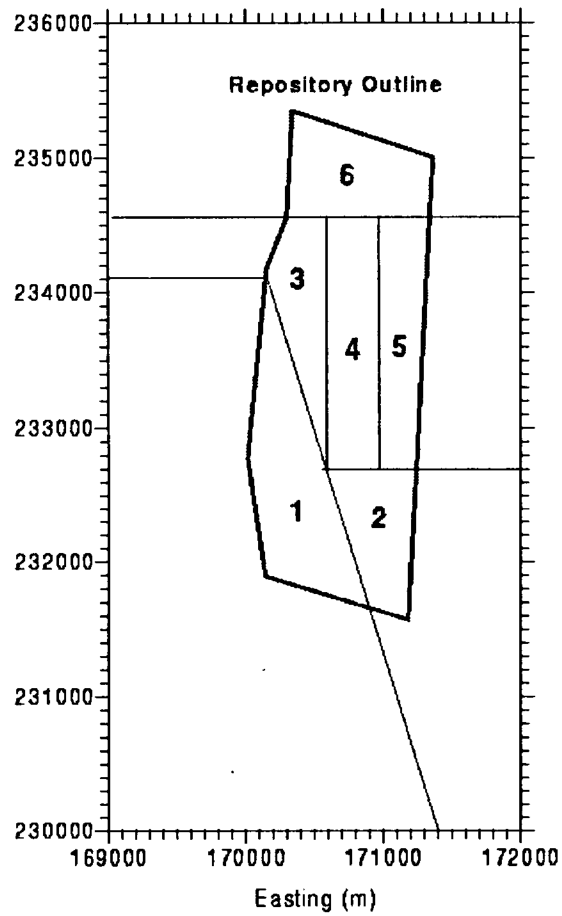
Unsaturated-Zone Transport

- Model is 3-D, DKM, particle tracker from FEHM
- Model uses flow fields, material properties, and X_{fm} from 3-D UZ flow model (TOUGH2)
- Model includes colloid-facilitated transport
- Affects SZ flow and transport component
- 9 key radionuclides are tracked
  - quick release and transport: ^{14}C, ^{99}Tc, ^{129}I
  - intermediate release and transport: ^{234}U, ^{237}Np , ^{79}Se
  - slow transport: ^{231}Pa
  - colloid transport: ^{239}Pu, ^{242}Pu

Discretization of UZ/SZ in TSPA-VA Model



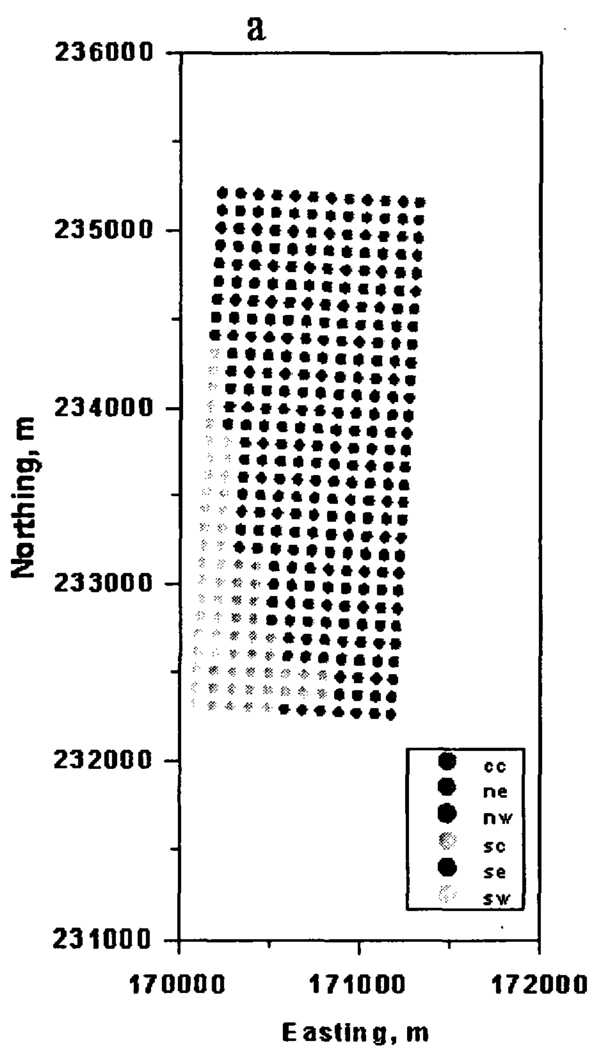


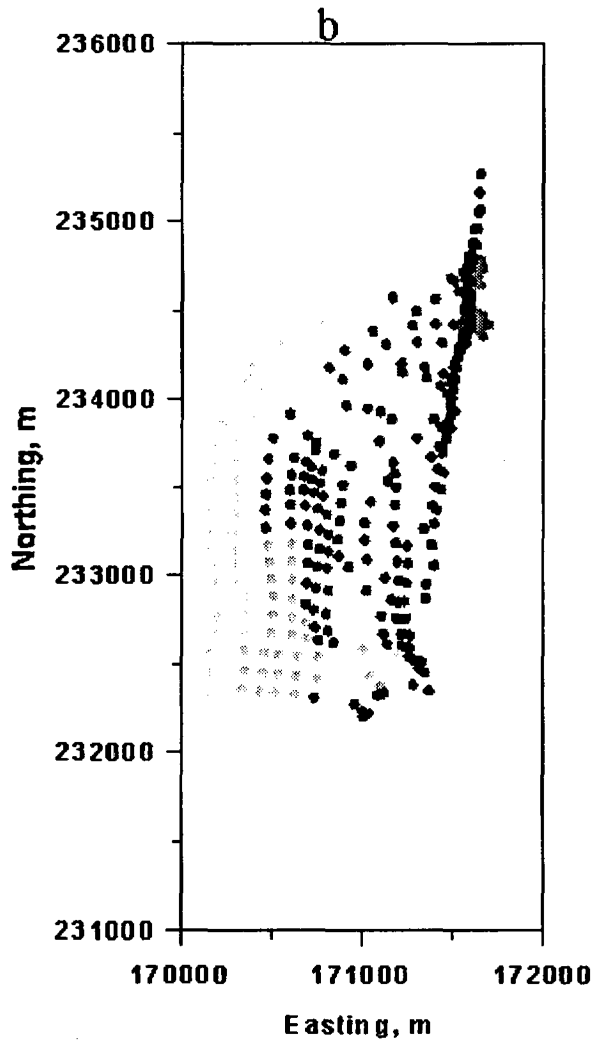


Source Regions at <u>Repository</u>
(feeding UZ transport model)

Source Regions at <u>Water Table</u>
(feeding SZ transport model)

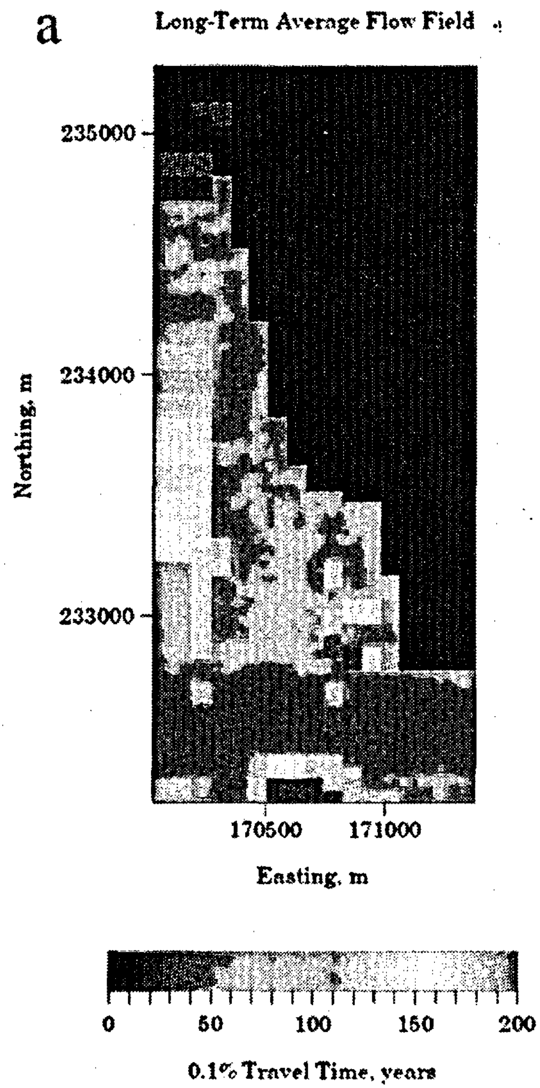
Travel Pathways in UZ
(present-day, no matrix diffusion)





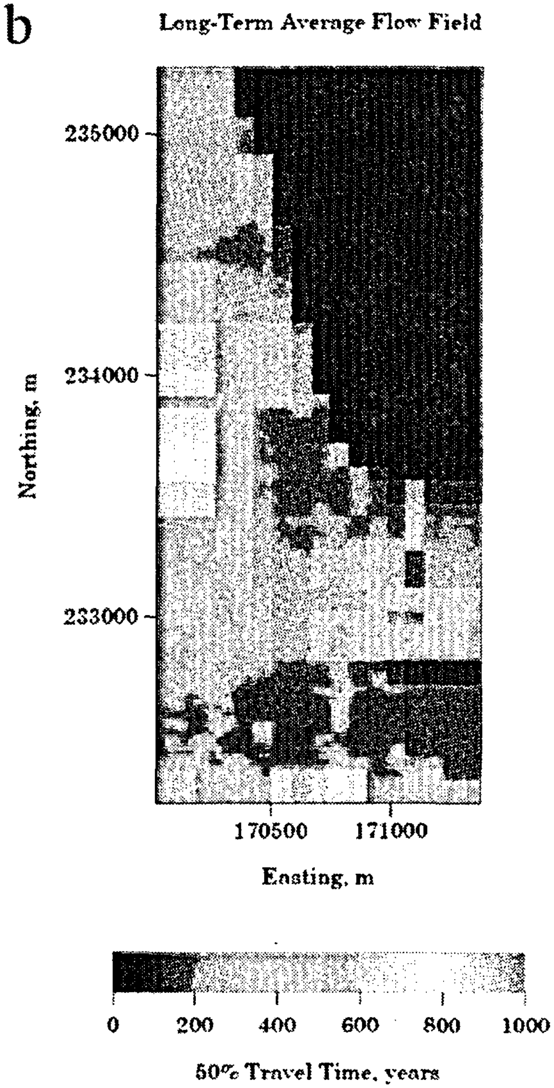
Travel Time Distributions
(long-term average, no matrix diffusion)

a



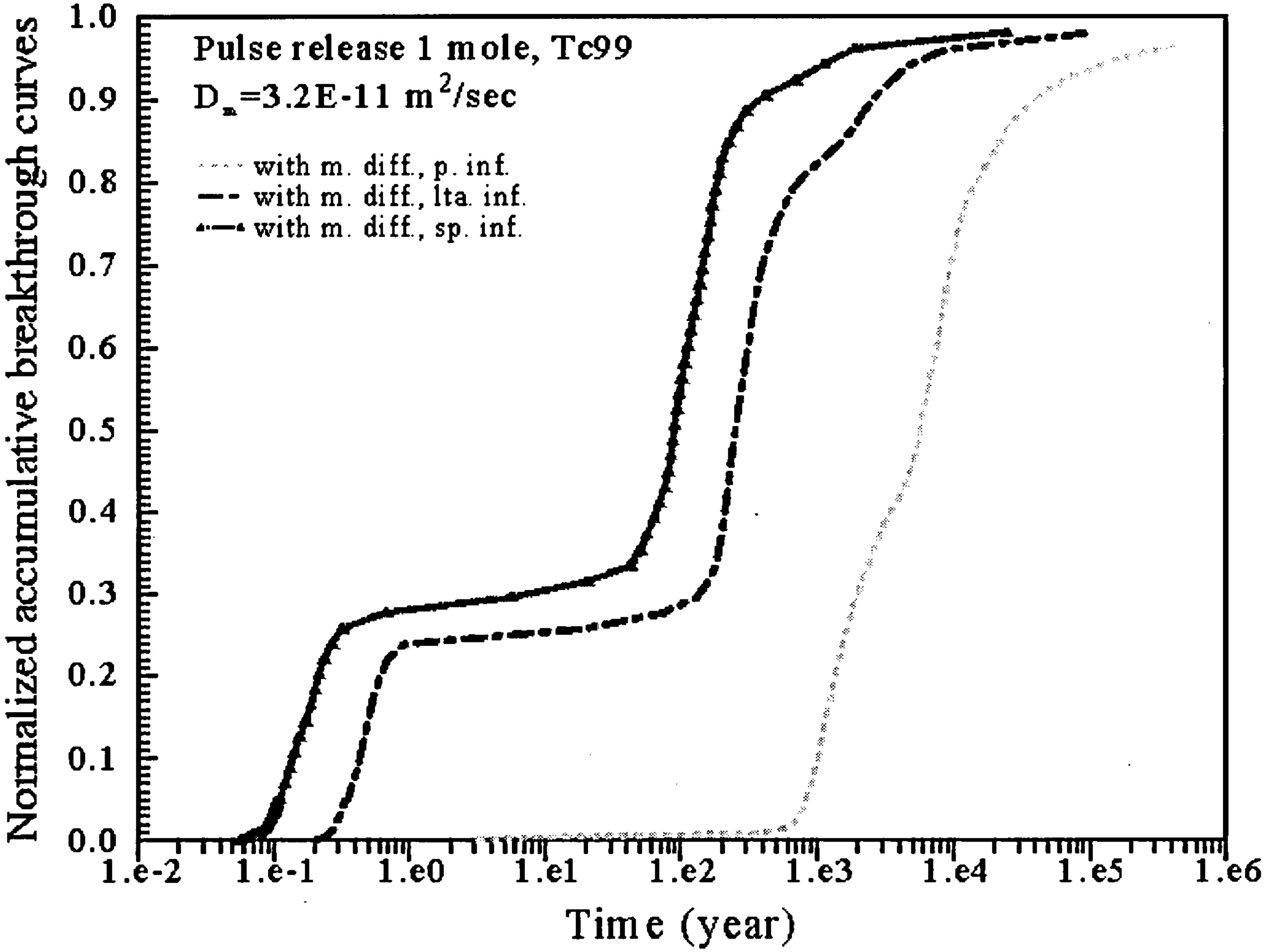
Note: color scales are different for the two plots.

b

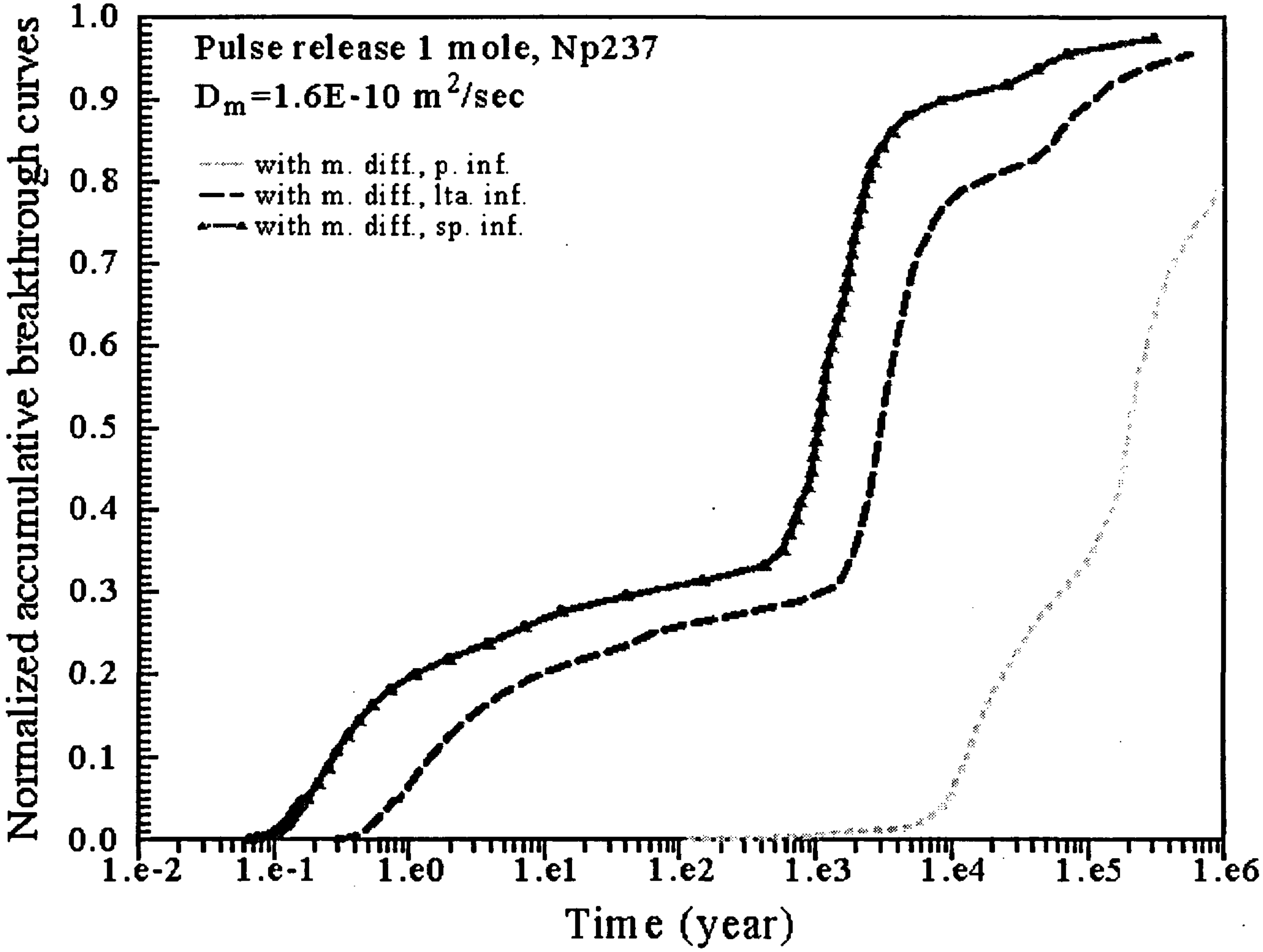


^{99}Tc Breakthrough Curves at Water Table

(various climate states)

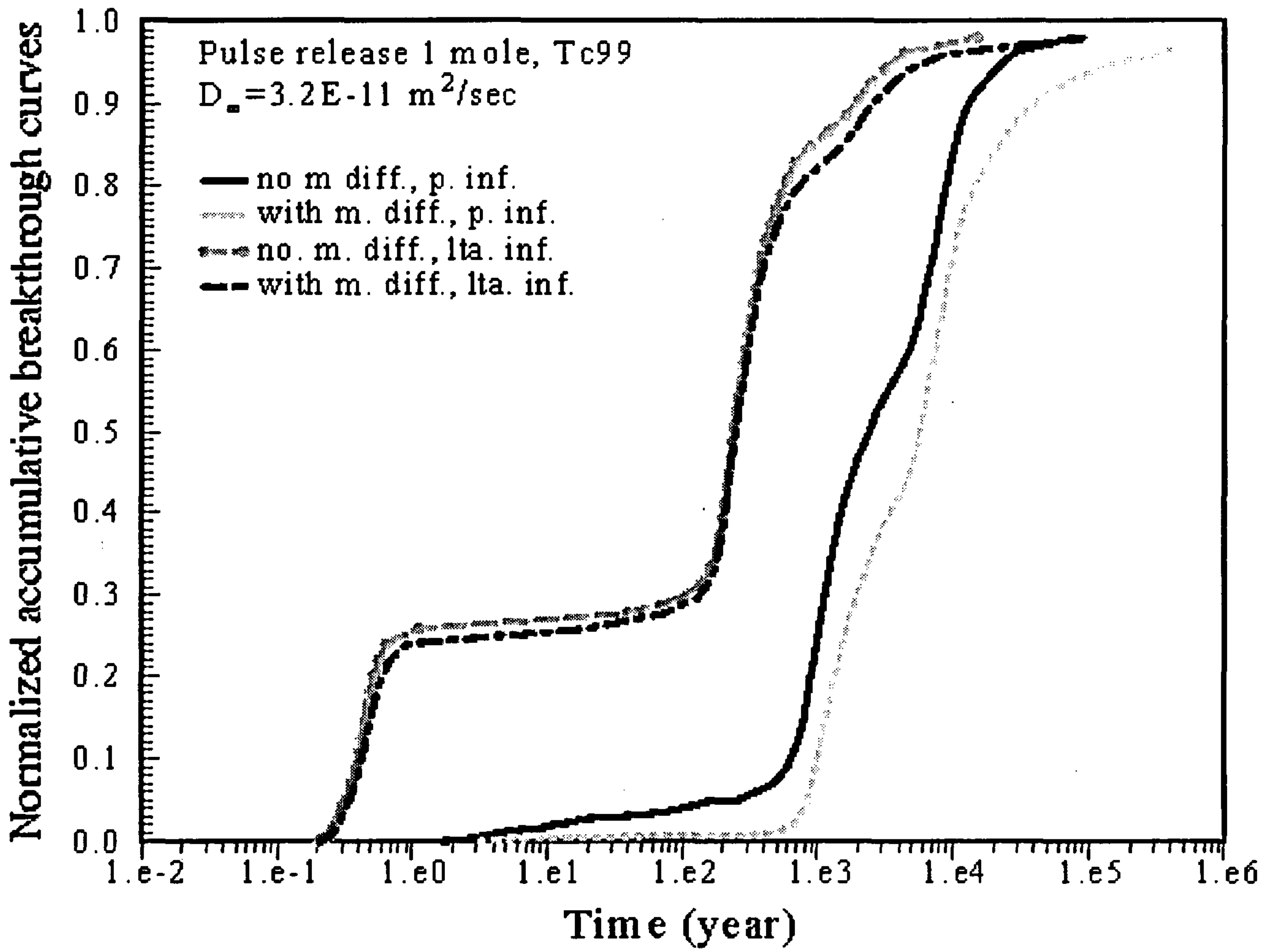


^{237}Np Breakthrough Curves at Water Table
(various climate states)

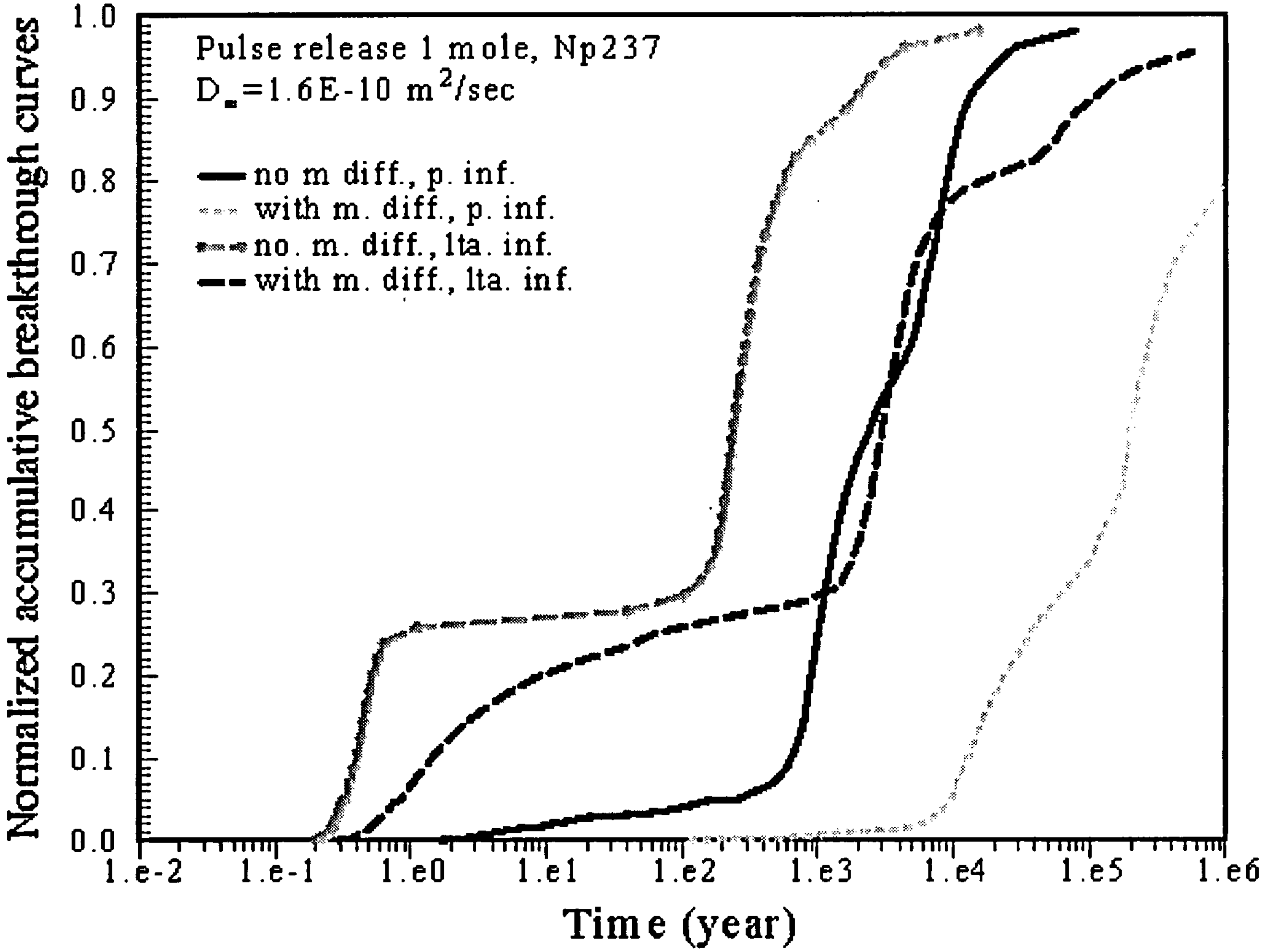


SENSITIVITY ANALYSES

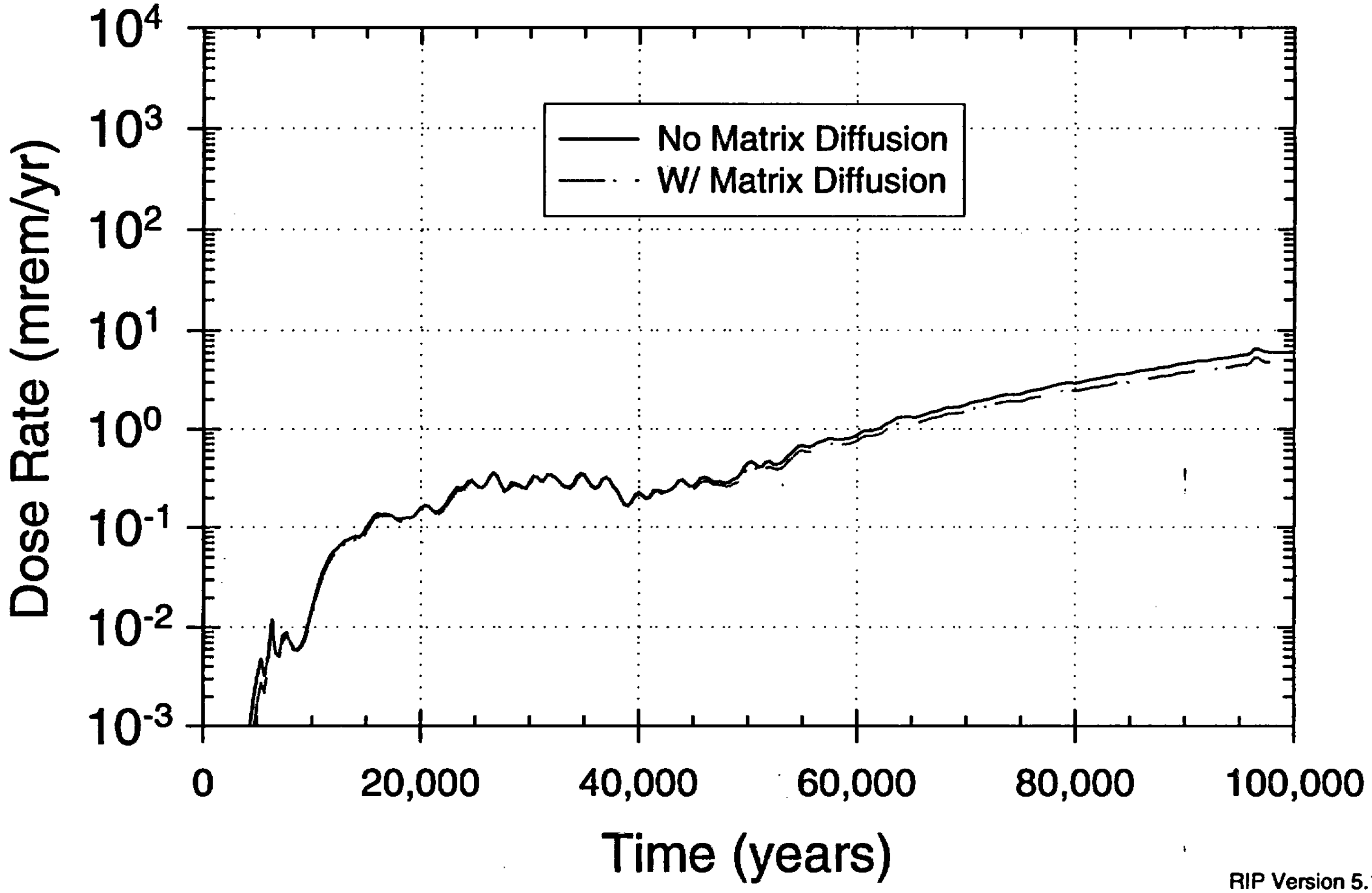
Effect of Matrix Diffusion on ^{99}Tc Breakthrough
(LTA climate vs. present-day climate)



Effect of Matrix Diffusion on ^{237}Np Breakthrough
(LTA climate vs. present-day climate)



Base Case: Matrix Diffusion Sensitivity
100,000-yr Expected-Value Dose-Rate History
All Pathways, 20 km



RIP Version 5.19
April 9, 1998
case33e5

Colloids

- Colloid-facilitated transport included in UZ and SZ transport components

- Only two isotopes of Pu considered for TSPA-VA

- Modeling based on laboratory data, scientific literature, and NTS observations

Underground Nuclear Events at NTS

Kersting, et al., 1997

Plutonium Migration at the Nevada Test Site (NTS)

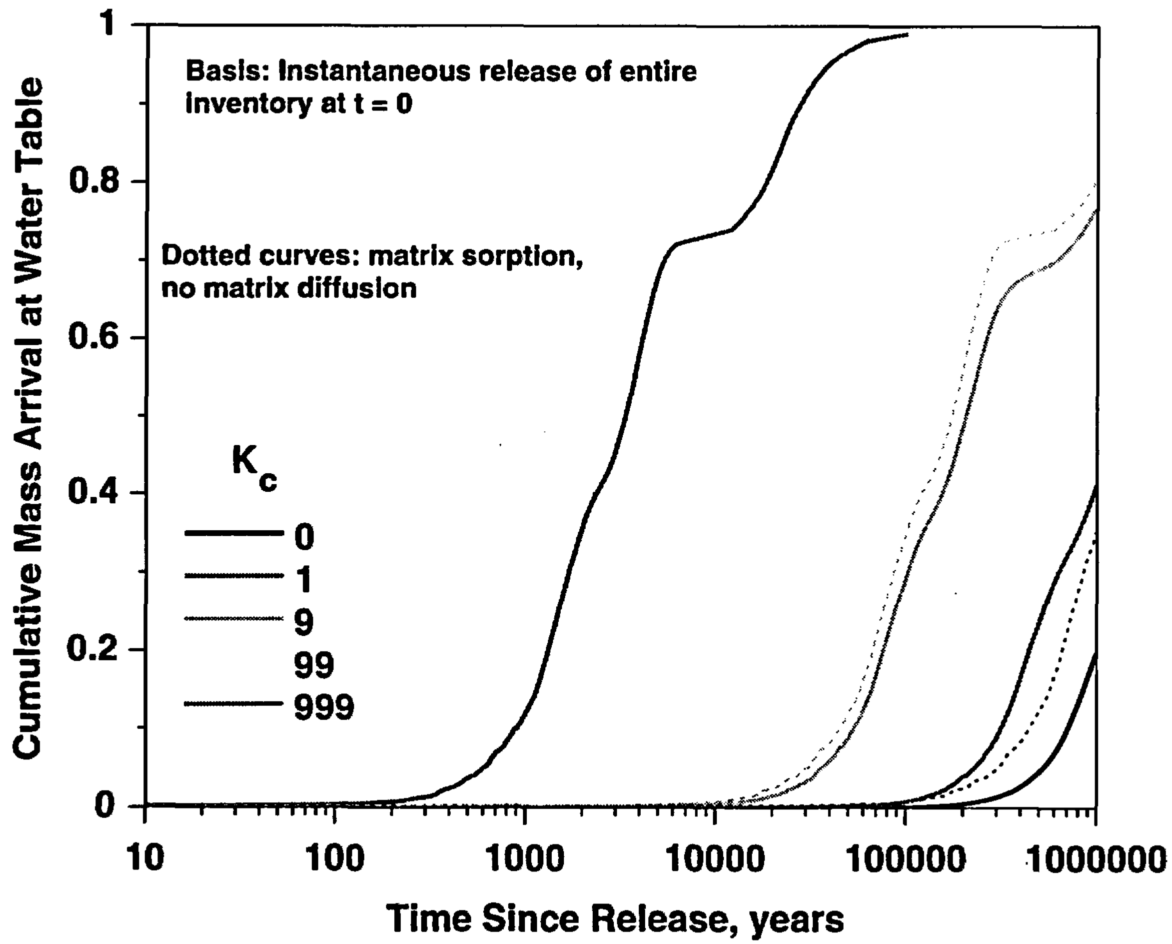
- Plutonium measured in groundwater at the NTS ER-20-5 wells at a maximum level of 0.63 pCi/L
- Ratio of Pu-240 to Pu-239 measured indicates that Pu originated at the nuclear test BENHAM
- BENHAM is located 1.3 km north of the ER-20-5 location
- BENHAM event fired on Pahute Mesa in December 1968 at a depth of 1,402 m below water table (at 641 m)
- Minimum distance of Pu migration at NTS is 1.3 km in 28 years
- Pu detected associated with the colloidal fraction
- Colloidal material isolated consisted mainly of clays, zeolites, and silica

Colloid-Facilitated Transport Modeling

- **Reversible sorption of radionuclides onto colloids**
  - instantaneous equilibrium assumed
  - a partitioning coefficient (K_c) is used to divide radionuclides between colloids and solute
  - $10^{-5} \le K_c \le 10$
  - a reversible-sorption model apparently cannot explain the BENHAM observations
- **Irreversible sorption of radionuclides onto colloids**
  - no filtration
  - path restricted to fractures
  - fraction of these "fast" radionuclides with respect to the amount released is uniformly sampled: $10^{-10} \le f_{fast} \le 10^{-4}$
  - f_{fast} □ 10^{-7} is the expected-value estimate based on the Benham observation of 0.63 pCi/L and the mean solubility of Pu in J-13 water

SENSITIVITY ANALYSES

Two-Dimensional Model Results
Colloid-Facilitated Transport of Plutonium

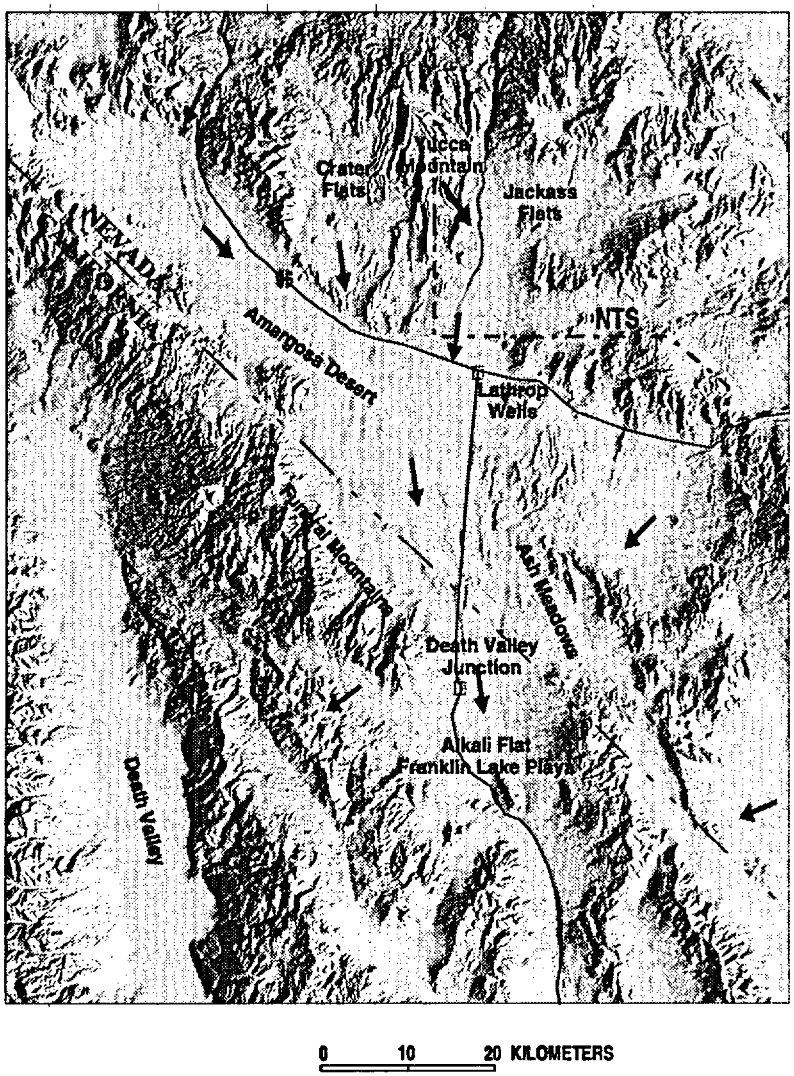


SZ Flow and Transport

- Affects biosphere component

- Multi-level modeling
  - 3-D model to determine paths
  - 1-D model to determine transport times
  - Convolution integral method to incorporate time-varying source
  - Dilution factor to determine final concentration

Regional SZ Groundwater Flow

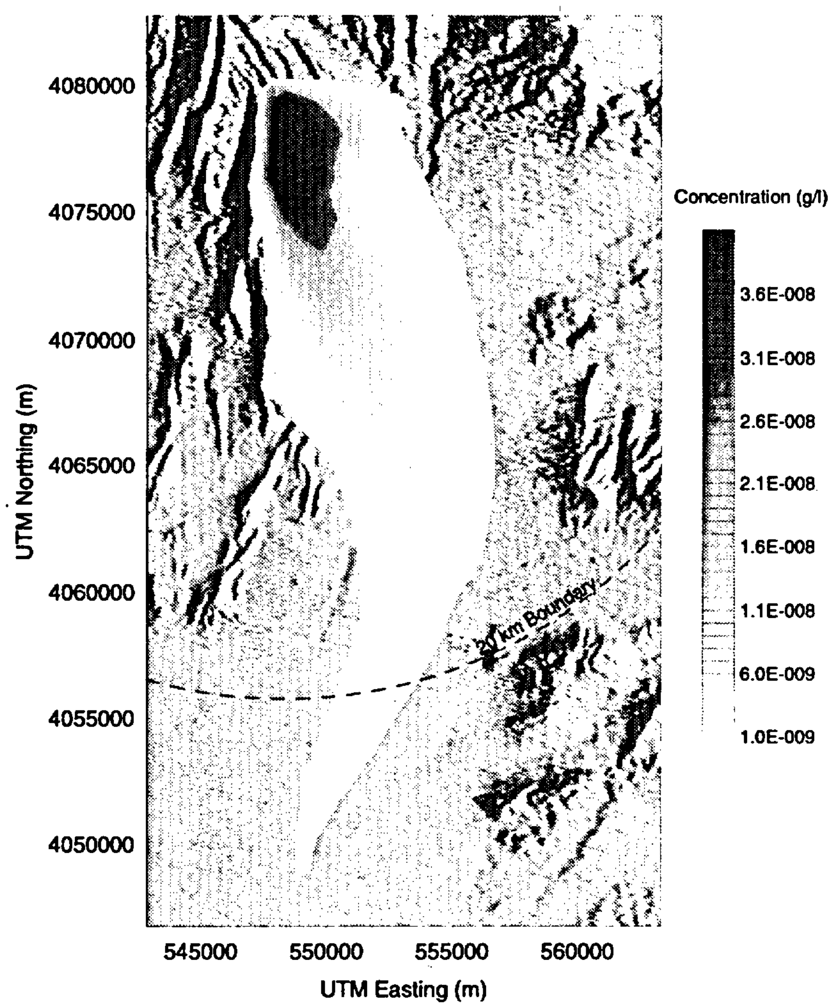


3-D Flow and Transport Modeling in the SZ

- **3-D SZ flow and transport modeling used to define the general direction of the radionuclide plume and the flowpath lengths through different hydrostratigraphic units for use in 1-D transport modeling.**

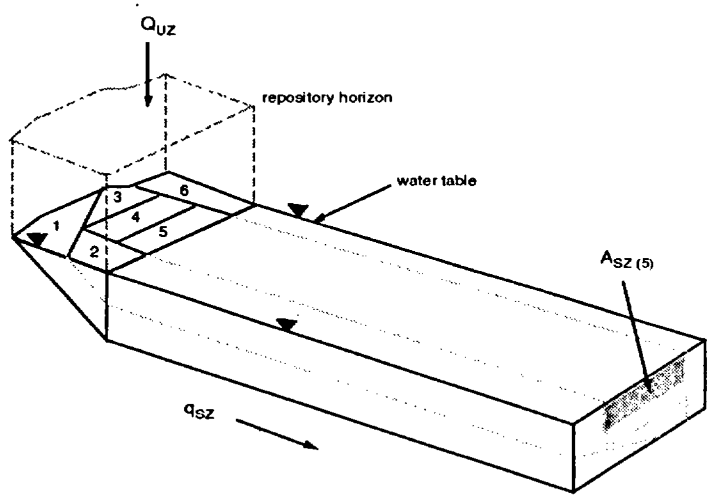
- **Steady-state flow and specified pressure boundary conditions assumed.**

- **Revised SZ site-scale geologic framework model employed.**

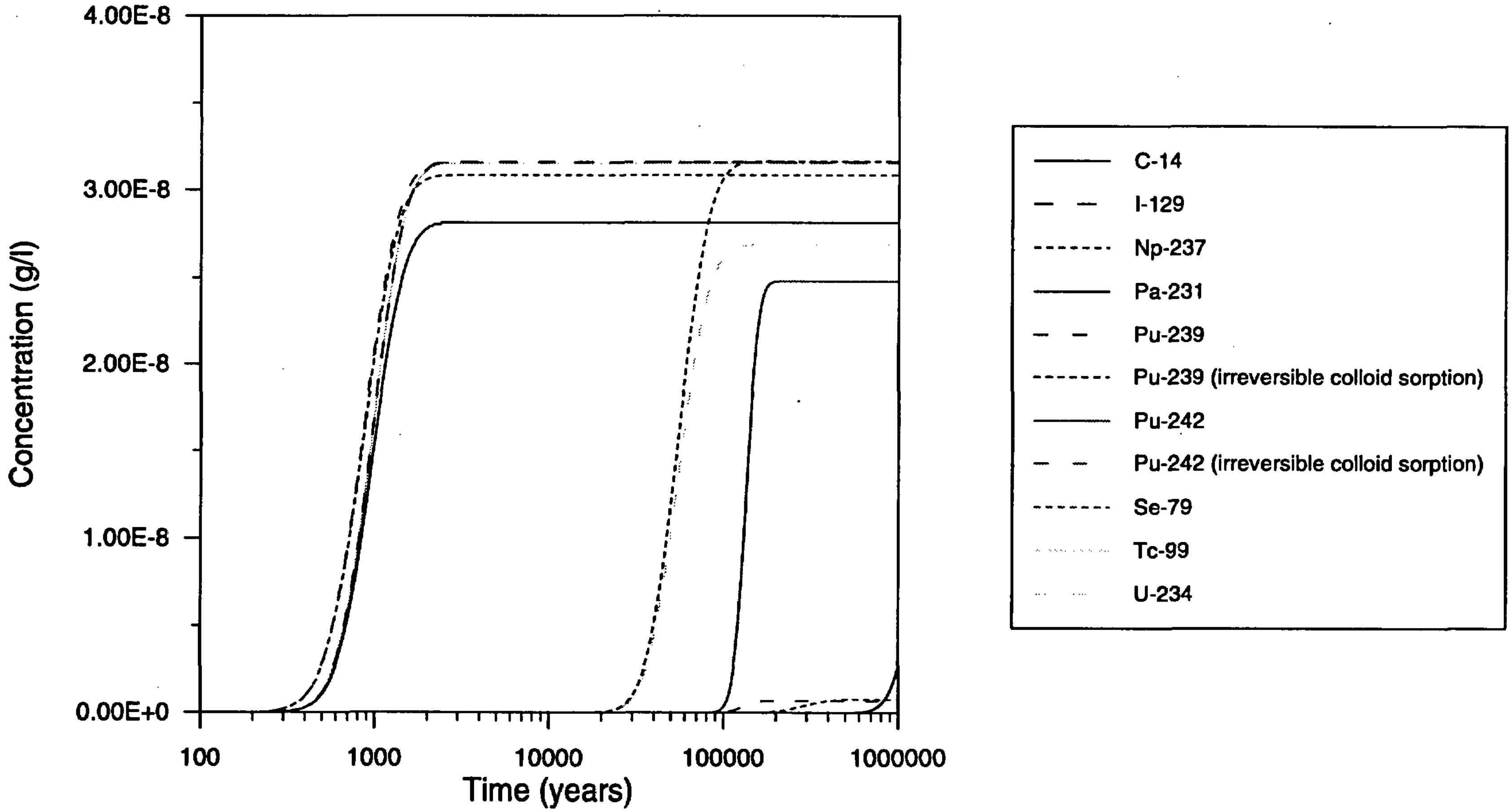


1-D Flow and Transport in the SZ

- Volumetric flux through each streamtube taken from UZ site-scale flow model at the water table.
- Specific discharge in the SZ set at 0.6 m\yr.
- Flowpath lengths through different units in SZ streamtubes taken from 3-D SZ flow and transport modeling. Fraction of flowpath length through alluvium/valley fill unit is varied.
- Transverse dispersion implicitly incorporated through a dilution factor.



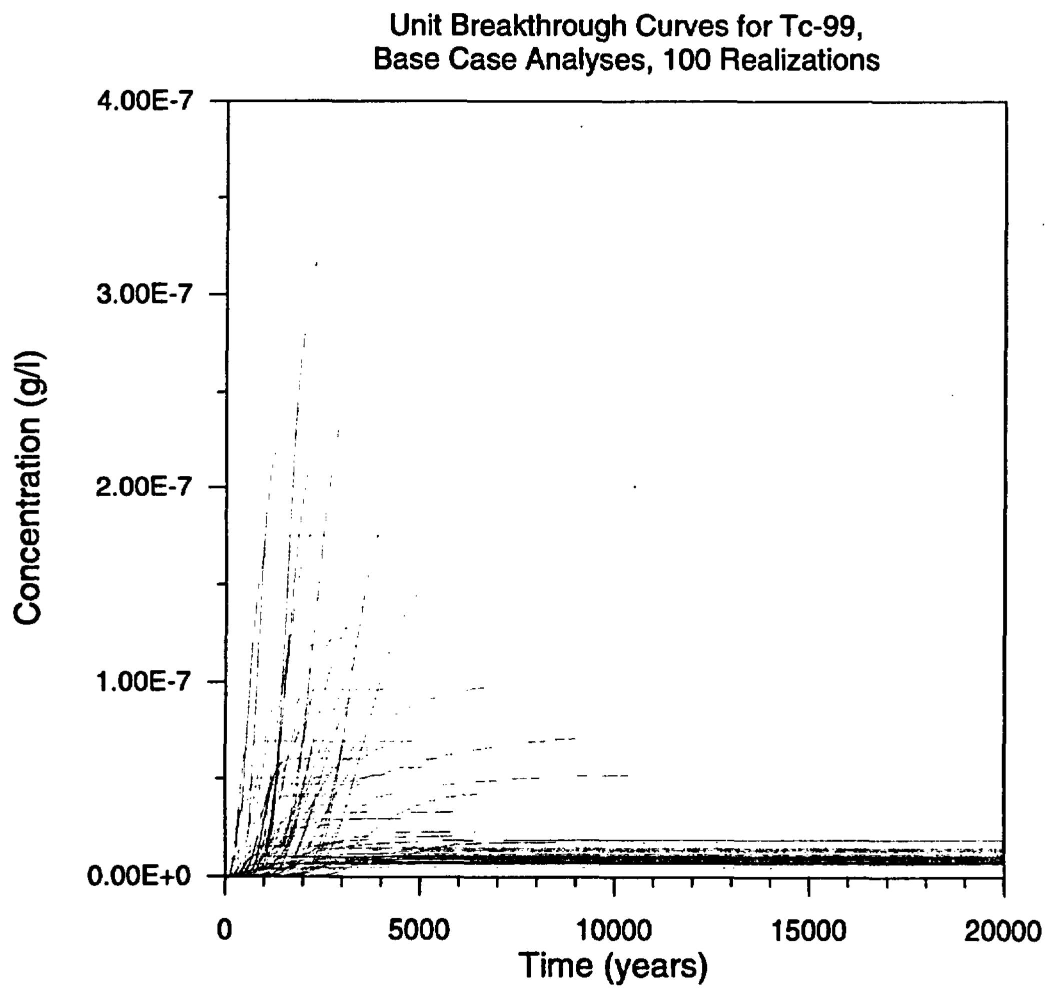
Unit Breakthrough Curves
(expected-value case)



Stochastic Parameters

- Dilution factor; discrete cdf [median=10]
- effective porosity (alluvium), truncated normal [0.25, 0.075]
- effective porosity (upper volcanic aquifer), log triangular [1e-5, 0.02, 0.16]
- effective porosity (upper volcanic confining unit), log triangular [1e-5, 0.02, 0.30]
- effective porosity (middle volcanic aquifer), log triangular [1e-5, 0.02, 0.23]
- Kd [Np] (alluvium), uniform [5.0, 15.0]
- Kd [Np] (volcanic), beta(exp) [1.5, 1.3]
- Kd [Pa] (volcanic), uniform [0.0, 100.]
- Kd [Se] (volcanic), beta(exp) [2.0, 1.7]
- Kd [U] (alluvium), uniform [5.0, 15.0]
- Kd [U] (volcanic), uniform [0.0, 4.0]
- Kd [Pa] (alluvium), uniform [0.0, 550.]
- Kd [Se] (alluvium), uniform [0.0, 150.]
- Kc [Pu], log uniform [1e-5, 1.0]
- longitudinal dispersivity, lognormal [2.0, 0.753]
- fraction of flowpath in alluvium, discrete cdf, uniform [0.0, 0.3], P[x=0.0]=0.1

Monte Carlo Realizations of 1-D Transport

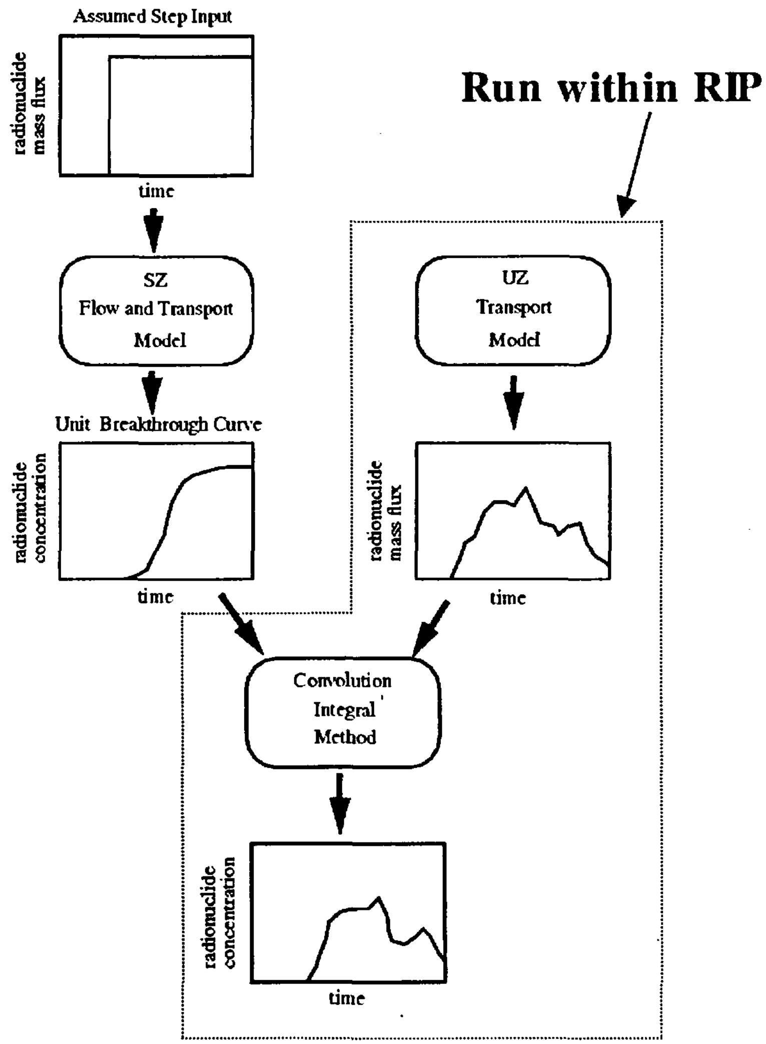


Convolution Integral Method for RIP Runs

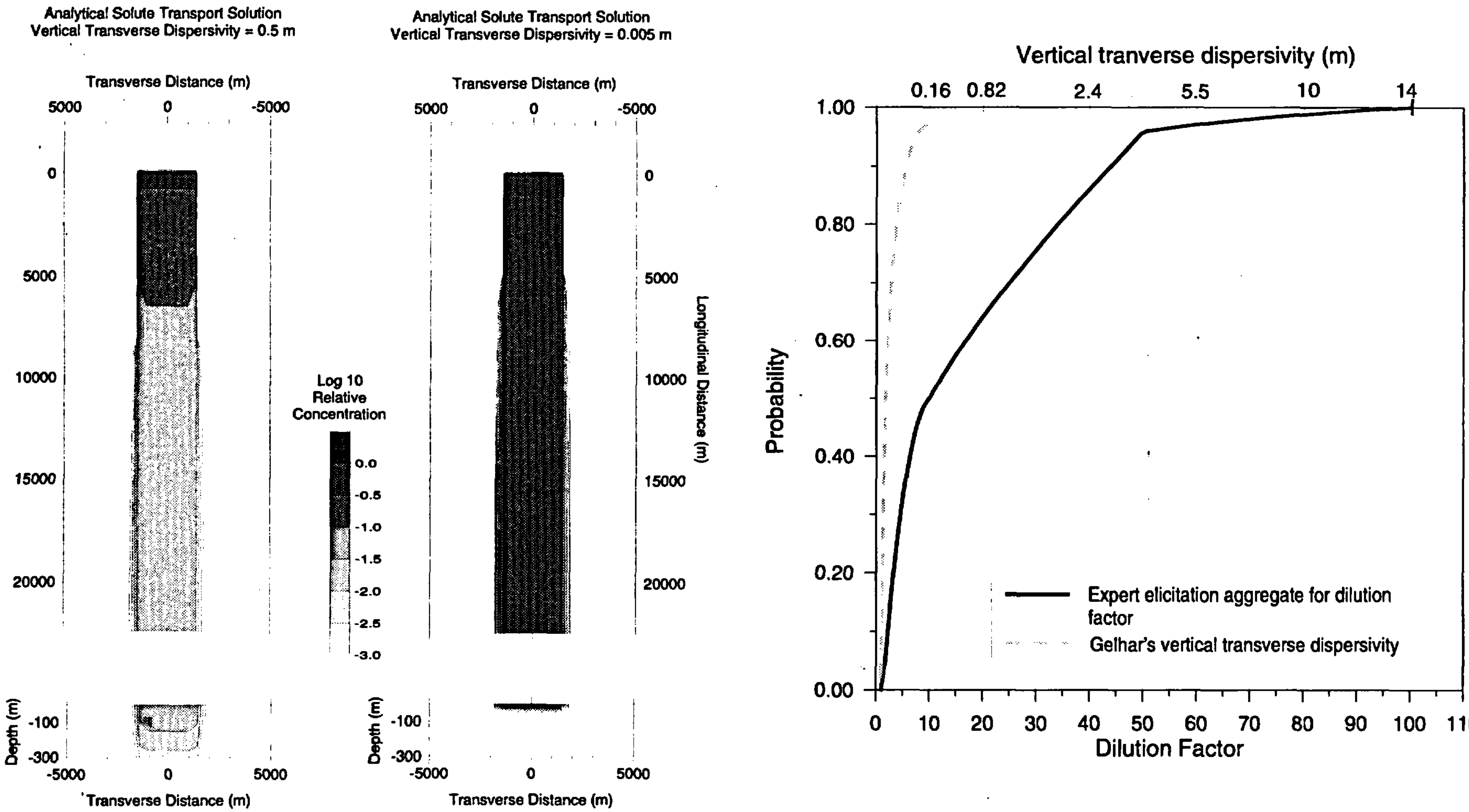
- Convolution integral method is a numerical shortcut for translating transient radionuclide mass flux from the UZ to radionuclide concentration history in the SZ 20 km downstream.

- Unit breakthrough curves are taken from a library of the 1-D transport simulation results.

- The impact of climate change is incorporated in the convolution method by scaling breakthrough curves for different climate states.



Sensitivity of Dilution Factor to Vertical Transverse Dispersivity

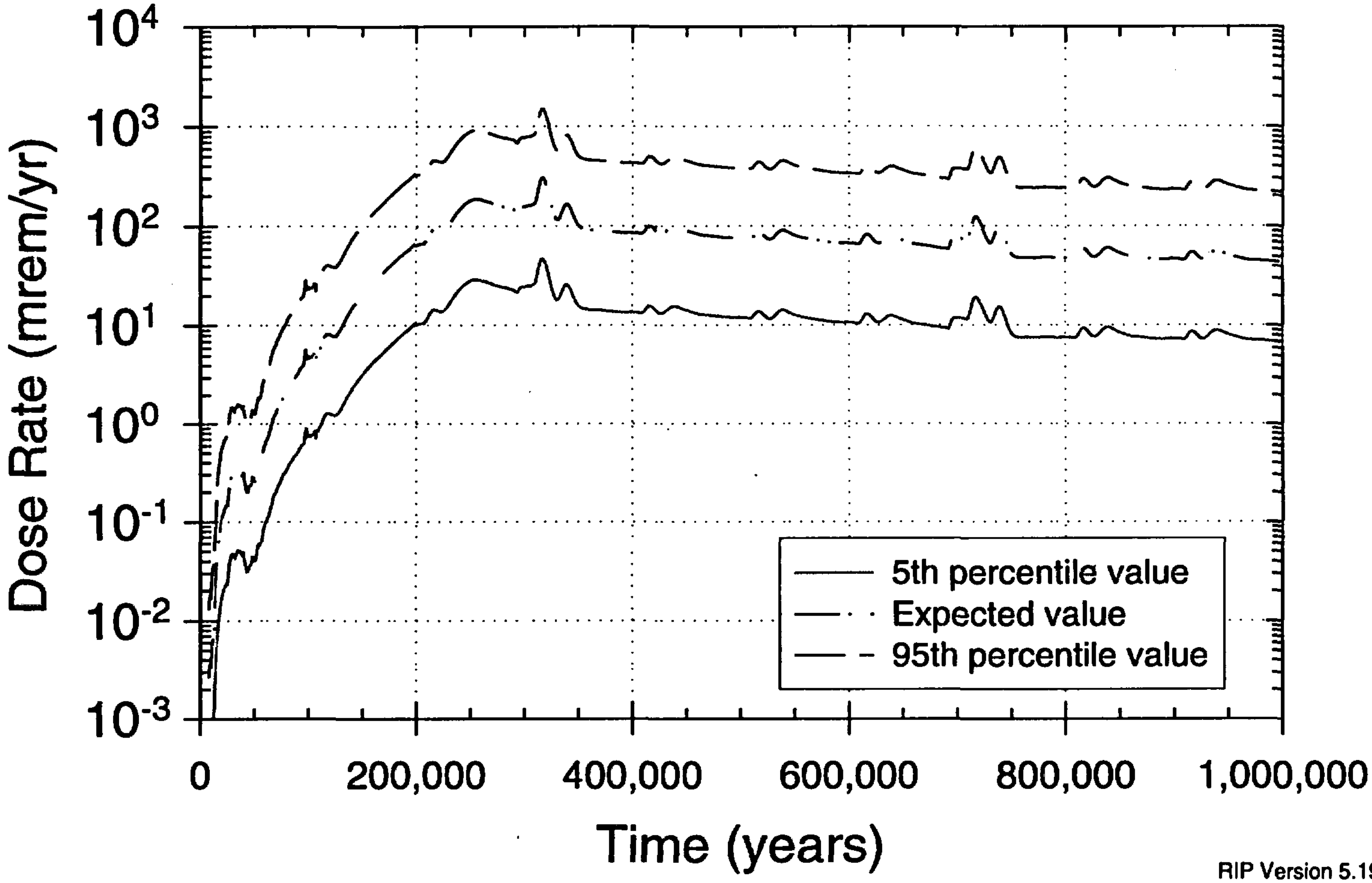


SENSITIVITY ANALYSES

5th and 95th Percentile SZ Dilution Factors

1,000,000-yr Expected-Value Dose-Rate History

All Pathways, 20 km



RIP Version 5.19
April 20, 1998
based on case0ee6

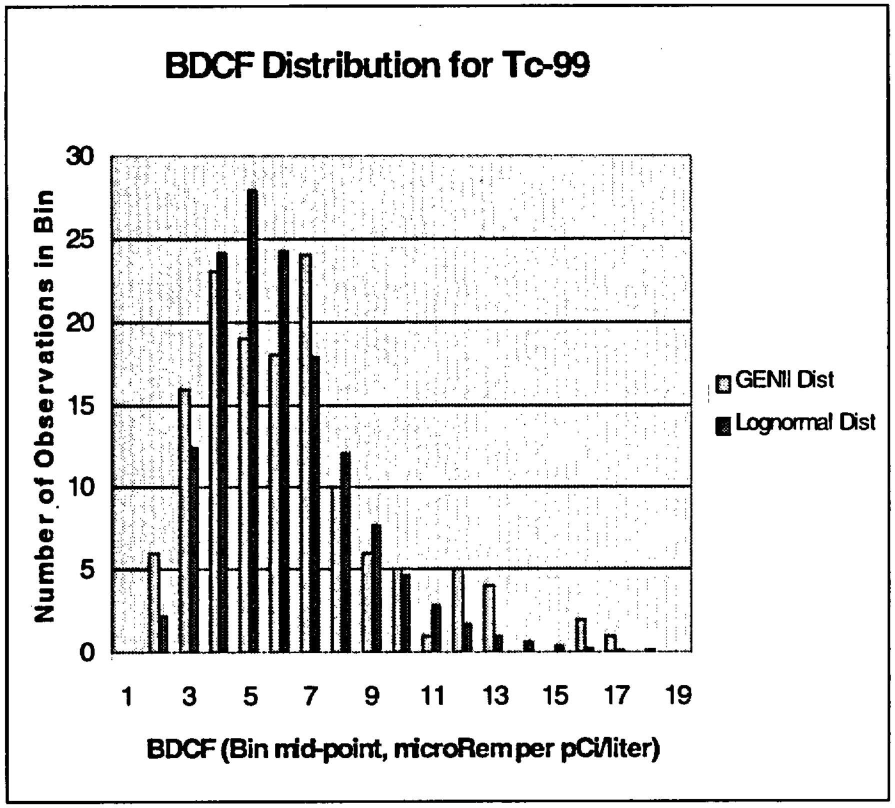
UZ-SZ-TRB98.PPT.125.NWTRB/4-23,24-98

Biosphere

- Final component – describes how an individual could be affected by radionuclide releases
- Major assumptions
  - farmer living 20 km from Yucca Mountain
  - present-day behavior will persist into the future
  - all water for household and agricultural uses comes from a well located at the point maximum radionuclide concentration
  - local food stuffs are consumed in the amounts determined for an average person by a site survey
  - other major parameters taken from accepted national (e.g., NRC, EPA, USDA) and international (e.g., ICRP, IAEA) sources
- GENII-S model
  - stochastic
  - 39 radionuclides (9 key radionuclides)
  - 3 climates
  - 3 receptors

Example of Predicted Biosphere Dose Conversion Factor (BDCF) Distribution

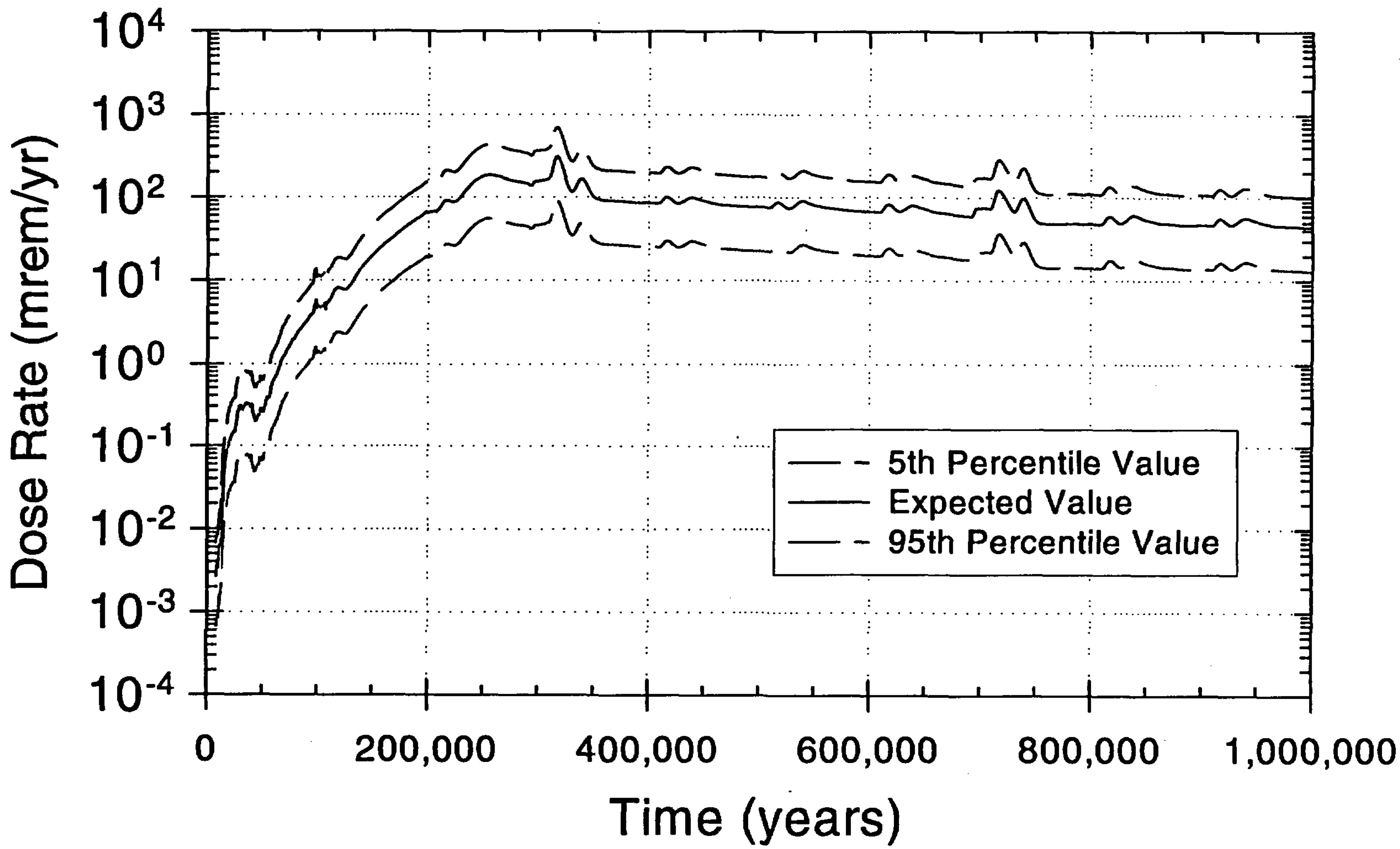
- Fitted Parameters for ^{99}Tc
- Best Fit: Log-normal
- Units: µrem per pCi/l
- Geom Mean: 5.6
- Geom Std Dev: 1.5
- Median: 5.8
- 95% CI for Geom
- Mean
- 5.3 to 6.0



SENSITIVITY ANALYSES

Sensitivity to Biosphere Dose Conversion Factors 1,000,000-yr Total Dose-Rate History

All Pathways, 20 km



YUCCA
MOUNTAIN
PROJECT

Traceability Example for TSPA-VA

Presented to:
NWTRB Panel on Performance Assessment
Albuquerque, New Mexico

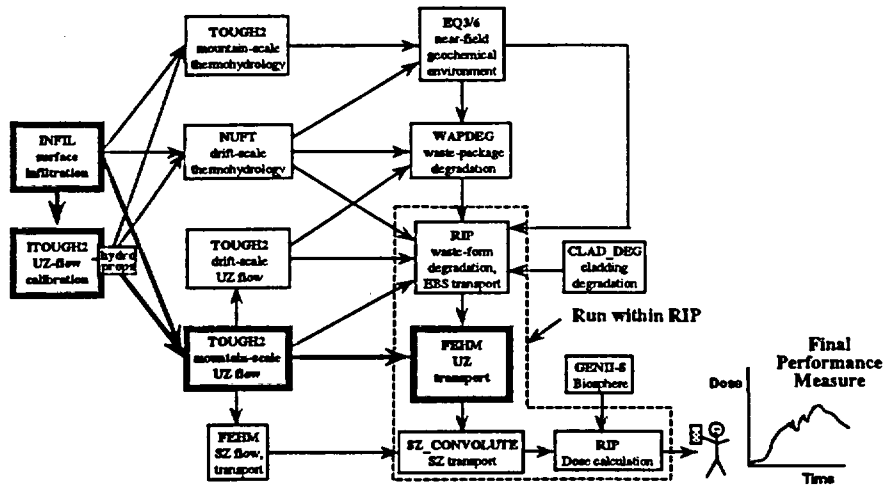
Presented by:
Clifford K. Ho
Sandia National Laboratories
Albuquerque, New Mexico

April 23-24, 1998

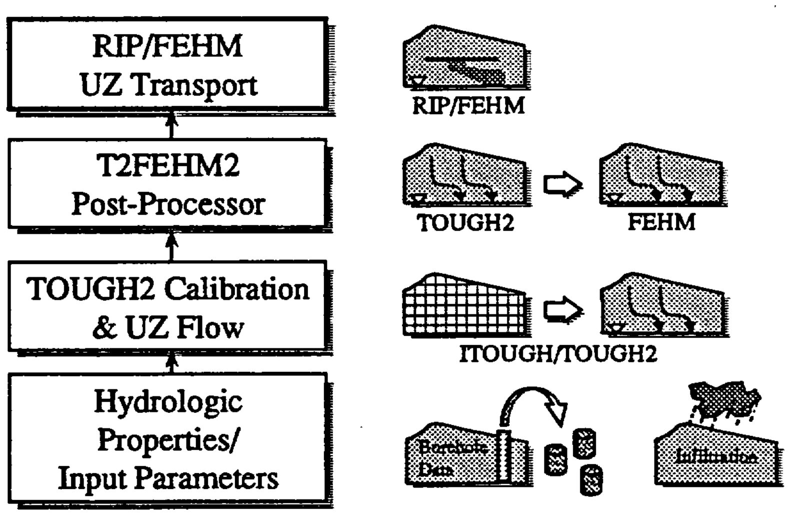
Definition and Objective

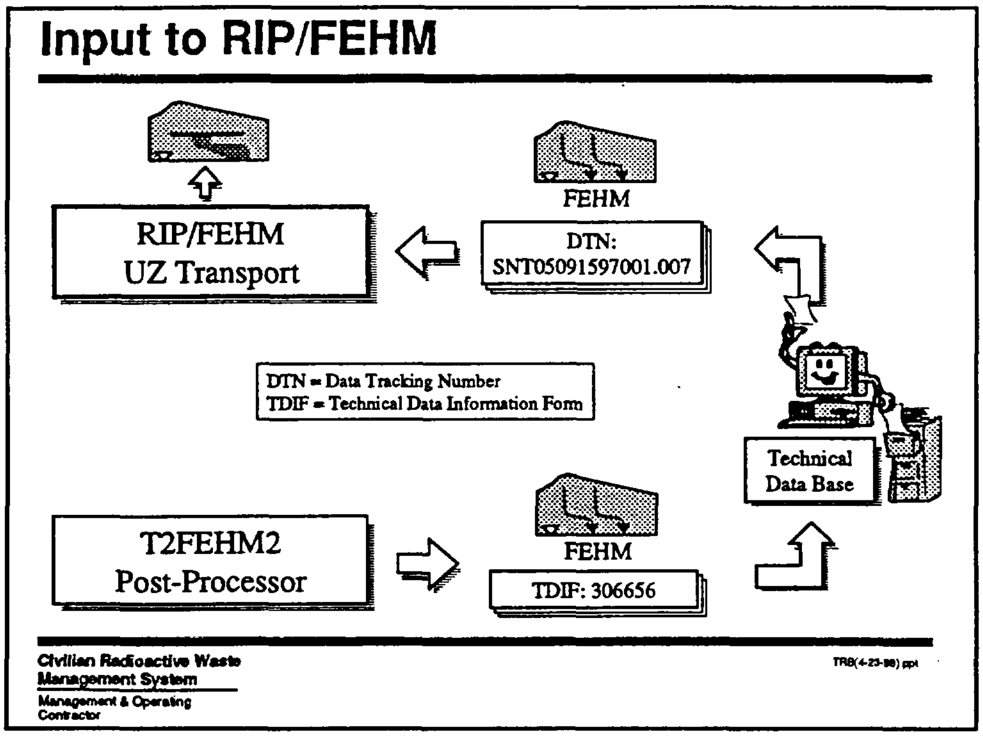
- trace´a·ble *adj.*
  - Able to ascertain the successive stages in the development or progress of.
- Demonstrate framework to produce traceable performance assessment calculations
  - Data and files are traceable and retrievable
  - Analyses can be reproduced

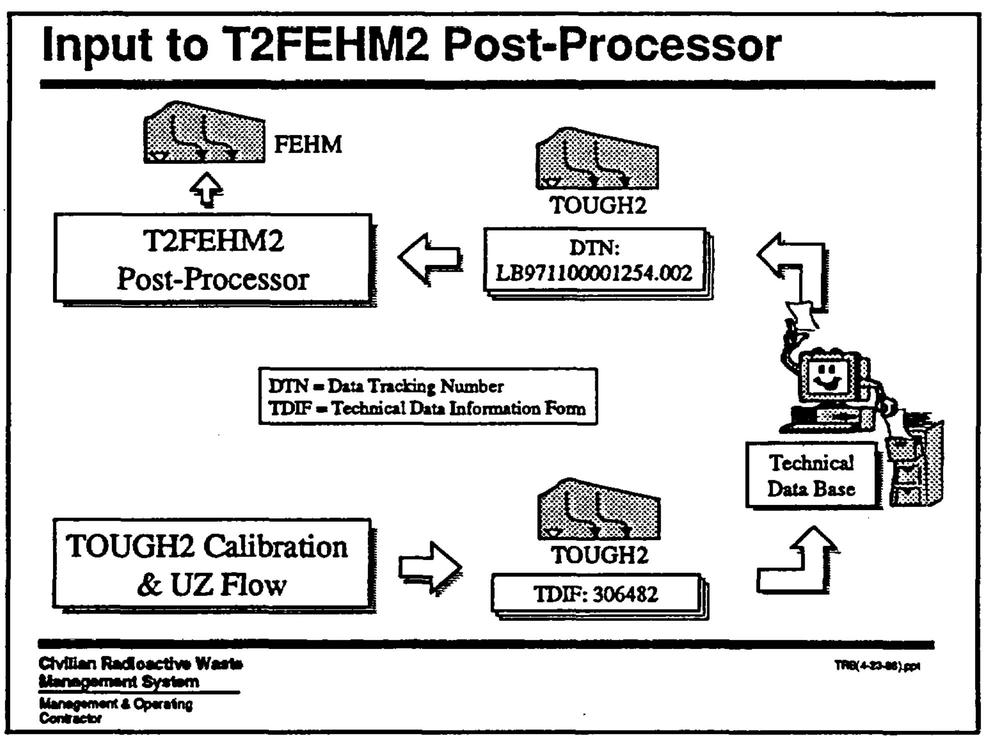
TSPA-VA Components



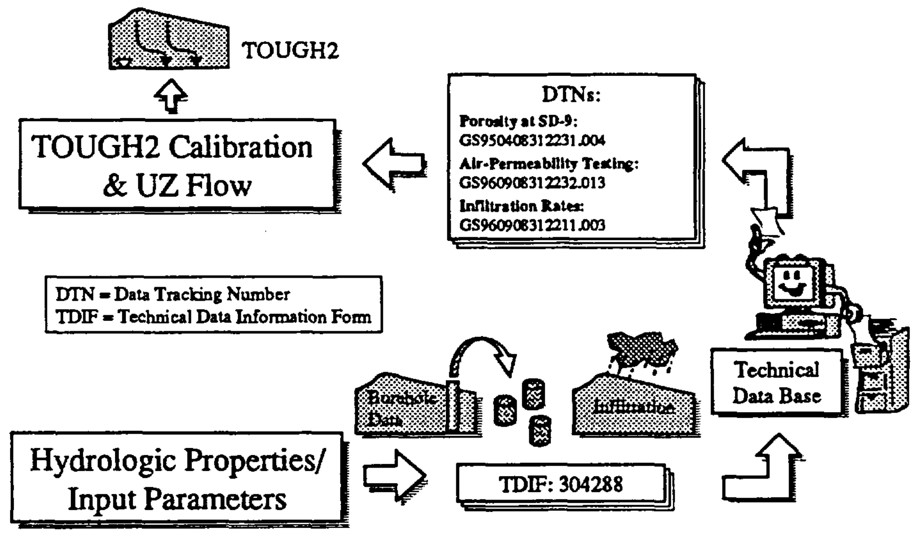
Unsaturated-Zone Flow and Transport




Input to RIP/FEHM
FEHM
RIP/FEHM
UZ Transport
DTN:
SNT05091597001.007
DTN = Data Tracking Number
TDIF = Technical Data Information Form
Technical
Data Base
T2FEHM2
Post-Processor
FEHM
TDIF: 306656
Civilian Radioactive Waste
Management System
Management & Operating
Contractor


Input to T2FEHM2 Post-Processor
FEHM
TOUGH2
T2FEHM2
Post-Processor
DTN:
LB971100001254.002
DTN = Data Tracking Number
TDIF = Technical Data Information Form
Technical
Data Base
TOUGH2 Calibration
& UZ Flow
TOUGH2
TDIF: 306482
Civilian Radioactive Waste
Management System
Management & Operating
Contractor

Input to TOUGH2 Calibration & UZ Flow



Summary

- Framework currently exists to provide traceability of TSPA-VA calculations
- Working towards traceability for all TSPA components

INFORMATION ONLY

306779

YMP-023-R4
05/06/96

YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT
TECHNICAL DATA INFORMATION

(Check one): ☐ ACQUIRED DATA (complete Parts I and II)
Data Tracking Number (DTN): ____________

☒ DEVELOPED DATA (complete Parts I, II and III)
Data Tracking Number (DTN): SNT05091597001.010

PART I Identification of Data

Title/Description of Data: TSPA-VA (TOTAL SYSTEM PERFORMANCE ASSESSMENT-VIABILITY ASSESSMENT) POST-PROCESSOR TO OBTAIN FRACTURE-MATRIX MULTIPLIERS FROM LBNL (LAWRENCE BERKLEY NATIONAL LABORATORIES) (UNSATURATED ZONE) UZ-FLOW FIELDS FOR USE IN UZ TRANSPORT.

Principal Investigator (PI): HO, C K
Last Name — First and Middle Initials

PI Organization: SANDIA NATIONAL LABORATORIES

Are Data Qualified?: ☐ Yes ☒ No Governing Plan: PAMP

SCPB Activity Number(s): ____________

WBS Number(s): 1.2.5.4.1

PART II Data Acquisition/Development Information

Method: USED A POST-PROCESSOR TO EXTRACT FRACTURE-MATRIX FLUX MULTIPLIERS THAT WERE USED IN THE UZ FLOW MODELS TO YIELD CONSISTENT FRACTURE-MATRIX INTERACTIONS IN THE TRANSPORT CALCULATIONS.

Location(s): SANDIA NATIONAL LABORATORIES - ALBUQUERQUE, NM

Period(s): 4/7/98 to 4/11/98
From: MM/DD/YY To: MM/DD/YY

Sample ID Number(s): N/A

PART III Source Data DTN(s)

LB971212001254.006	LB971212001254.009	
LB971212001254.007	LB971212001254.010	—
LB971212001254.008		

Comments

SNL DATASET ID: 52/T05-09/15/97. THIS DATA IS NQ BECAUSE THE DATA DEVELOPMENT PROCESS WAS NOT A QA ACTIVITY.

Checked by: *Eloise James* (Signature) Date: 4/13/98

YAP-SIII.3Q.1

Manager's Note

Technical Databases

ATDT: Automated Technical Data Tracking
Database Definition

GI: Geographic Information
Database Definition

RIB: Reference Information Base
Database Definition

SEP: Site and Engineering Properties
Database Definition

Datasets

EIS: Environmental Impact Statement
Dataset Definition

LAD: License Application Data
Dataset Definition

RDI: Repository Design Input
Dataset Definition

SCD: Site Characteristics Data
Dataset Definition

SPA: System Performance Assessment
Dataset Definition

VAD: Viability Assessment Data
Dataset Definition

Managed Databases

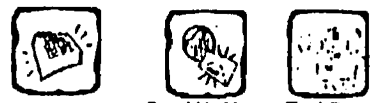
CST: Chemical Species Thermodynamics
Database Definition

MWD: Modeling Warehouse Data
Database Definition

RTN: Requirements Traceability Network
Database Definition

SCC: Standards, Constants, and Conversions
Database Definition

WFC: Waste Form Characteristics
Database Definition



30-Day Posted Data Changes Send Us Your Comments TechData Contacts

Return to M&O Nevada Page

Last updated April 8, 1998

Input Data for LBNL Site-Scale UZ Flow Model

TYPE OF DATA USED	DATA SOURCE/ PRINCIPAL INVEST.	GENERAL DESCRIPTION	DTN	QA Status
Geologic Framework (only Q data summarized here; complete listing of Q & NQ data given in Bandurraga, 1996)	Geslin & Moyer (1994)	NRG-2c lithologic log	GS940308314211.012	Q
	Geslin & Moyer (1994)	NRG-2d lithologic log	GS940308314211.013	Q
	Geslin & Moyer (1994)	NRG-7/7a litho. log	GS940408314211.020	Q
	Geslin et al. (1994)	Summary of litho. logs	GS940308314211.009	Q
	Moyer & Mongano (1994a, 1994b)	SD-9 lithologic log	GS940808314211.041	Q
		SD-9 lithologic log	GS941108314211.052	Q
	Moyer et al. (1995)	Summary of litho. logs	GS941208314211.060	Q
	Moyer & Geslin (1994a)	UZ N-11 litho. log	GS940308314211.010	Q
	Moyer & Geslin (1994b)	UZ N-15,-16,-17 logs	GS940308314211.019	Q
	Moyer & Geslin (1994c)	UZ N-36 litho. log	GS940308314211.018	Q
	Moyer & Geslin (1994d)	UZ N-38 litho. log	GS940308314211.011	Q
	Moyer & Geslin (1994e)	UZ N-63 litho. log	GS940308314211.017	Q
	Moyer & Geslin (1994f)	UZ N-64 litho. log	GS940308314211.016	Q
	Moyer et al. (1993)	North Ramp Tiva litho.	GS931108314211.044	Q
	Rautman & Engstrom (1996a, b)	SD-7 geology	SNT02110894001.002	Q
		SD-12 geology	SNT02012894001.002	Q
	Zimmerman & Buesch (1995)	UZ-7a lithologic log	GS950908314211.034	Q
Thermal Properties	Brodsky et al. (1997)	Thermal-k	SNL01A05059301.005	Q
Matrix Properties: Saturation, Moisture Potential, Porosity, Rock Grain Density, Van Genuchten param.	L. Flint (1997)	ESF Alcoves 2, 3, 4, 6	GS961008312231.009	Q
	L. Flint (1995)	SD-7	GS951108312231.009	Q
	L. Flint (1995)	SD-9	GS950408312231.004	Q
	L. Flint (1995)	SD-12	GS950308312231.002	Q
	L. Flint (1995)	UZ-14	GS950408312231.005	Q
	L. Flint (1995)	UZ#16	GS940508312231.006	Q
	L. Flint (1995)	UZ#16, N27	GS950608312231.008	Q
	L. Flint (1995)	NRG-6	GS950608312231.007	Q
	L. Flint (1995)	NRG-7a	GS951108312231.010	Q
	Moyer et al. (1994)	SD-9/12, N31/32	GS941208314211.060	Q
Fracture Data (only Q data summarized here; complete listing of Q & NQ data given in Ch. 7 of Bodvarsson et al., 1997)	Detailed Line Survey (DLS) – Stations in meters along the ESF. Data collected by USGS/BR.	DLS 0+60 to 4+00	GS950508314224.002	Q
		DLS 4+00 to 8+00	GS950808314224.004	Q
		DLS 8+00 to 10+00	GS951108314224.005	Q
		DLS 10+00 to 18+00	GS960408314224.002	Q
		DLS 18+00 to 26+00	GS960608314224.006	Q
		DLS 26+00 to 30+00	GS960608314224.007	Q
		DLS 35+00 to 40+00	GS960808314224.011	Q
		DLS 40+00 to 45+00	GS960708314224.010	Q
		DLS 45+00 to 50+00	GS960808314224.013	Q
	Anna (1996)	Tiva Canyon Tuff	GS960408312281.001	Q
	Anna (1997)	Topopah Spring Tuff	GS970208312281.001	Q
	Sweetkind & Williams-Stroud (1996)	synthesis of fract. data	GS960808314224.010	Q
	Sweetkind (1995)	Fran Ridge	GS950108314222.001	Q
	Kessel (1995a)	SD-12	SNF29041993002.071	Q
	Kessel (1994)	NRG-7a	SNF29041993002.015	Q
	Kessel (1995b)	NRG-7a	SNF29041993002.048	Q
Pneumatic/Air-k	G. LeCain (1997)	Air-permeability	GS960908312232.013	Q
	G. Patterson (1996a)	*In situ* gas pressure	GS960908312261.004	Q
	G. Patterson (1996b)	*In situ* gas pressure	GS960908312261.003	Q
	G. Patterson (1996c)	*In situ* gas pressure	GS960208312261.001	Q
	J. Rousseau (1996)	*In situ* gas pressure	GS960308312232.001	Q

Input Data for LBNL Site-Scale UZ Flow Model

TYPE OF DATA USED	DATA SOURCE/ PRINCIPAL INVEST.	GENERAL DESCRIPTION	DTN	QA Status
Temperature	J. Rousseau (1996)	*In situ* temperature – UZ#4/5, UZ-7a, NRG-6, NRG-7a, SD-12	GS960308312232.001	Q
	Sass et al., 1988	Borehole temperature logs	GS950408318523.001/ NNA.1989.0123.0010	Non-Q
Geochemical	Fabryka-Martin et al. (1996a, b)	$^{36}Cl/Cl$	MOL.19970211.0035	TBQ
	Z. Peterman (1997)	$^{87}Sr/^{86}Sr$	GS970308315215.006	Q
	Levy et al. (1997)	chloride and $^{36}Cl/Cl$	LASL831222AQ97.001	Q
	Yang et al. (1996)	chemical/isotopic data	GS970108312271.001	Q
	Peterman & Stuckless (1993)	rock chemistry	GS930108315213.005	Q
	Peterman et al. (1992)	Sr isotopes	GS920208315215.009	Q
	Carlos et al. (1995)	Fracture-coatings	MOL.19960306.0564	Q
Perched Water	G. O'Brien (1996)	G-2 pumping test	GS960508312312.006	Q
	R. Luckey (1996)	UZ-14 pumping test	GS960308312312.005	Q
Variable Infiltration Maps	Flint et al. (1996)	Infiltration rates	GS960908312211.003	Q

YUCCA
MOUNTAIN
PROJECT

Analysis of Disturbed Events for TSPA-VA

Presented to
NWTRB
Panel on Performance Assessment: TSPA-VA
Albuquerque, New Mexico

Presented by:
Ralston W. Barnard
Sandia National Laboratories
Albuquerque, New Mexico

April 23-24, 1998

Outline

- Disturbed Events
- Disturbed Scenarios Analyzed for TSPA-VA

Disturbed Events

- Disturbances have a probability of occurrence less than 1
  - generally of low probability (10^{-7} – 10^{-8} per year)
  - initiator is an event (earthquake, volcano) or change in conditions (criticality)
- Disturbed scenarios do not include expected changes
  - e.g., climate

Disturbed Scenarios Analyzed for TSPA-VA

- Igneous activity
- Seismic activity
- Nuclear criticality
- Human intrusion

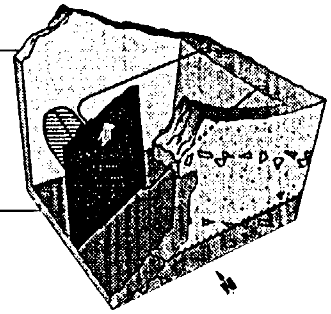
Igneous Activity

- Direct releases at surface from volcano
- Increased source term for groundwater transport from effects of intrusion
- Altered SZ transport from regional intrusion

TSPA-VA Analysis of Direct Volcanic Releases

- Emphasis placed on calculating the radionuclide source term
  - source term incorporates physical processes required to mobilize waste in eruptive stream
- Analysis of radionuclide dispersal uses CNWRA code (ASHPLUME)
- Performance measure is dose at receptor point 20 km S of repository

Igneous Activity Scenarios



Igneous intrusion occurs in YM Area?

No: *No performance assessment consequence. End Scenario.*

Yes

Magmatic dike intrudes into repository?

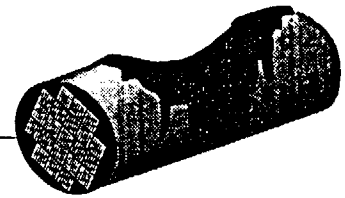
No: *No performance assessment consequence.*

Yes

Dike intrusion directly contacts waste packages?

No: *No performance assessment consequence.*

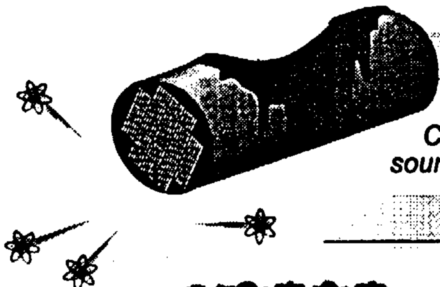
Yes



Waste packages are breached?

No: *No performance assessment consequence.*

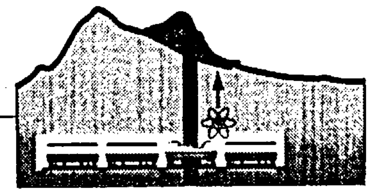
Yes



Waste is removed from waste package?

No: *Contaminated basalt increases groundwater transport source term. Modeled in enhanced source term scenario.*

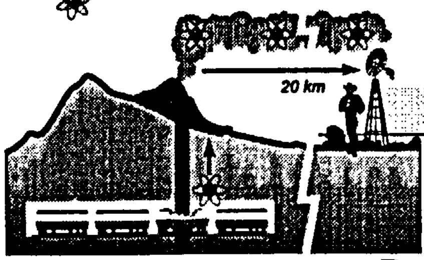
Yes



Waste is entrained to surface in ascending ash?

No: *Performance assessment consequence modeled by enhanced source term scenario.*

Yes



Waste is dispersed in ash plume?

No: *Performance assessment consequence not modeled.*

Yes

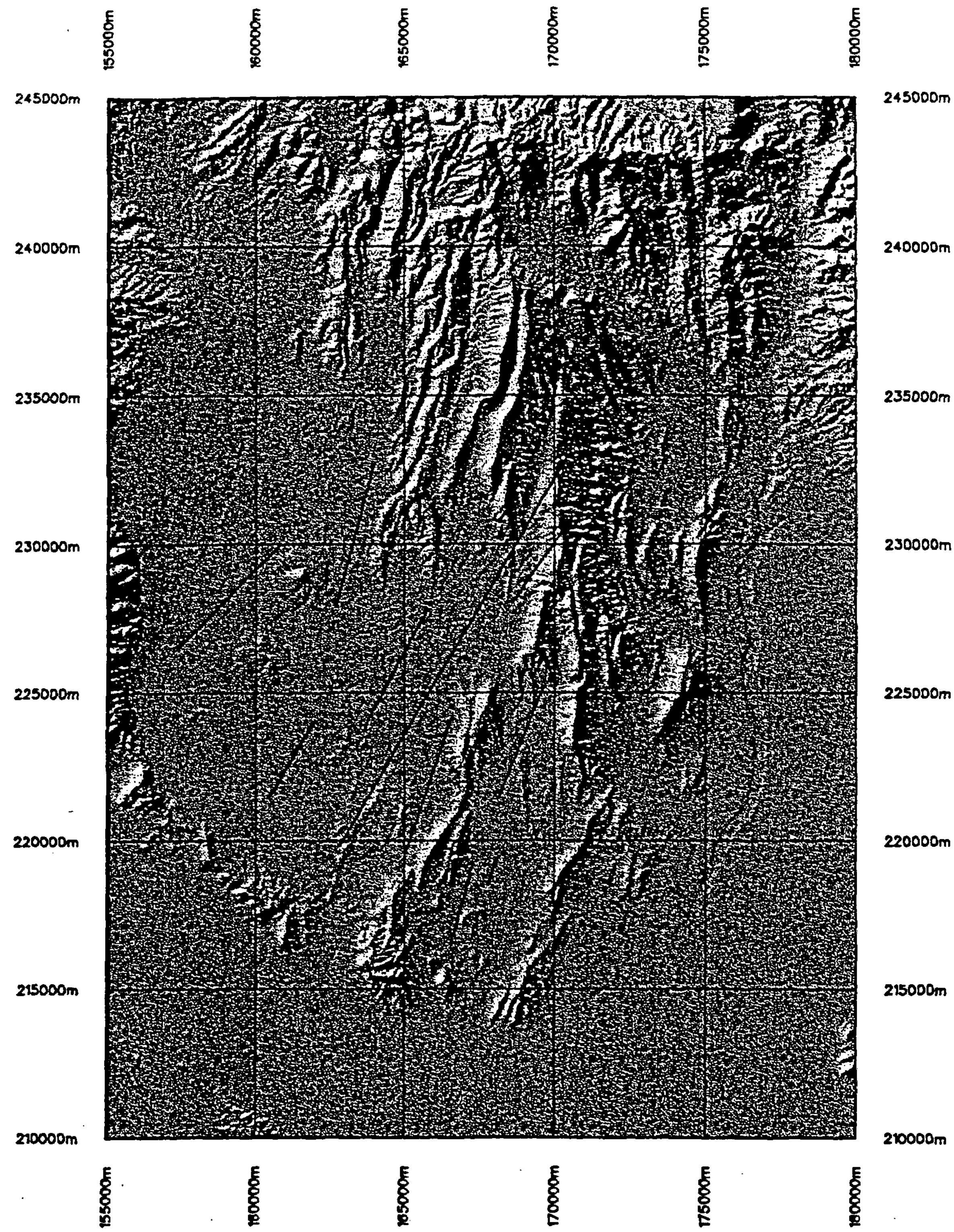
Doses at receptor site used as performance assessment consequence.

snl/trw abq 02.eps

Source-Term analysis

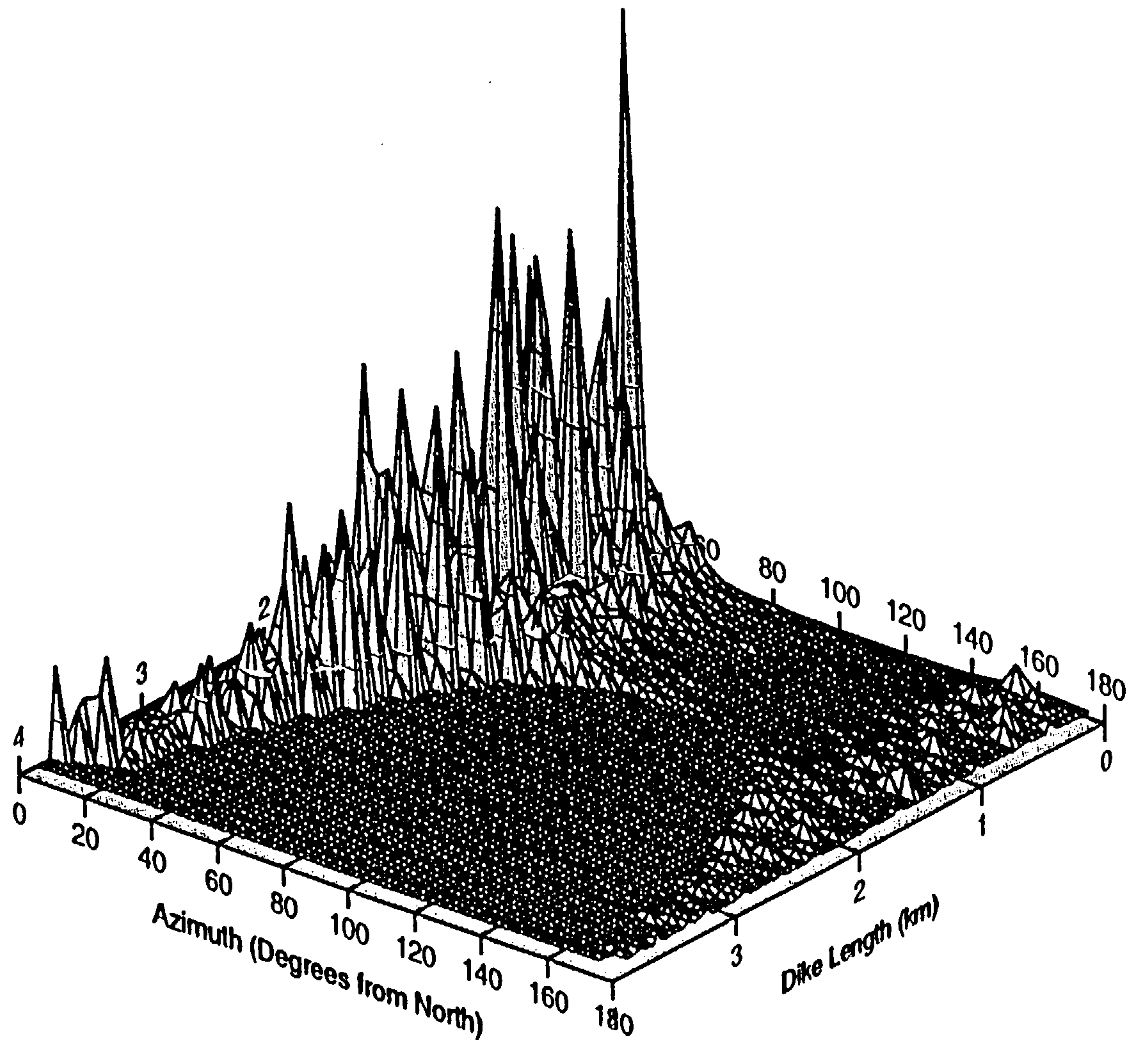
Intrusion Characteristics

- Intrusion locations from PVHA work
  - dike length and orientation
- Other intrusion plumbing parameters developed with inputs from YMP volcanic experts (Greg Valentine, Frank Perry, LANL)
  - dike width
  - number of vents in repository
  - fragmentation depth
  - eruption duration, volume, magma properties



Note: Map grid is based on Nevada (Central) State Plane Coordinate System

Joint Probability Distribution Function for Instrusion Length and Orientation

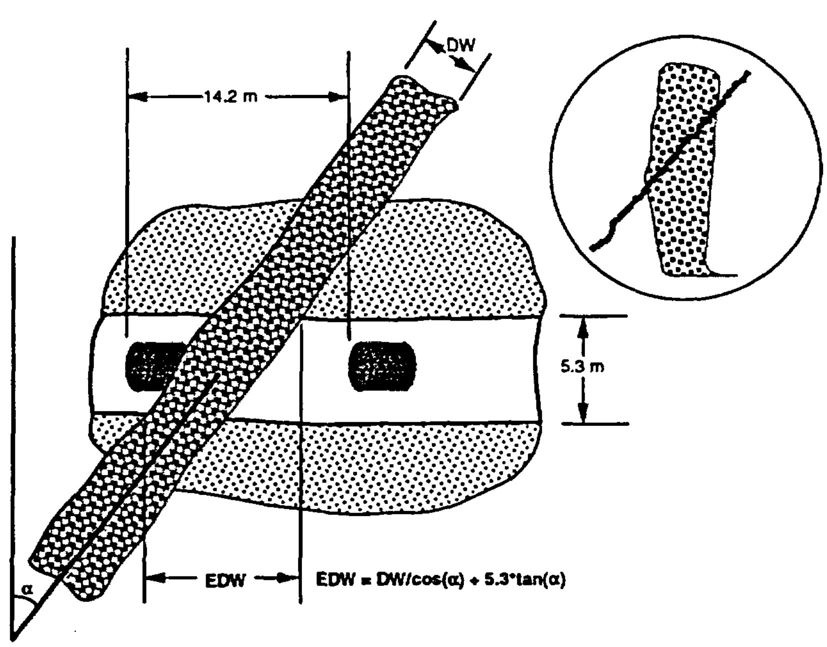


Source Term (Continued)

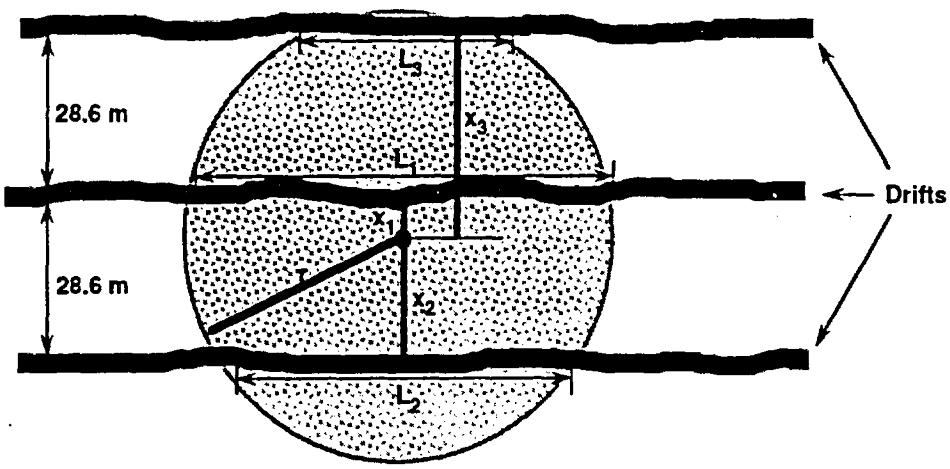
Interaction of Intrusion and Waste Packages

- For direct releases, intrusion must directly contact waste packages
  - near misses are for the enhanced source term scenario
- Interaction can be between either liquid magma or "ash"

Intersection of Dike and Drifts



Intersection of Eruptive Conduit with Drifts

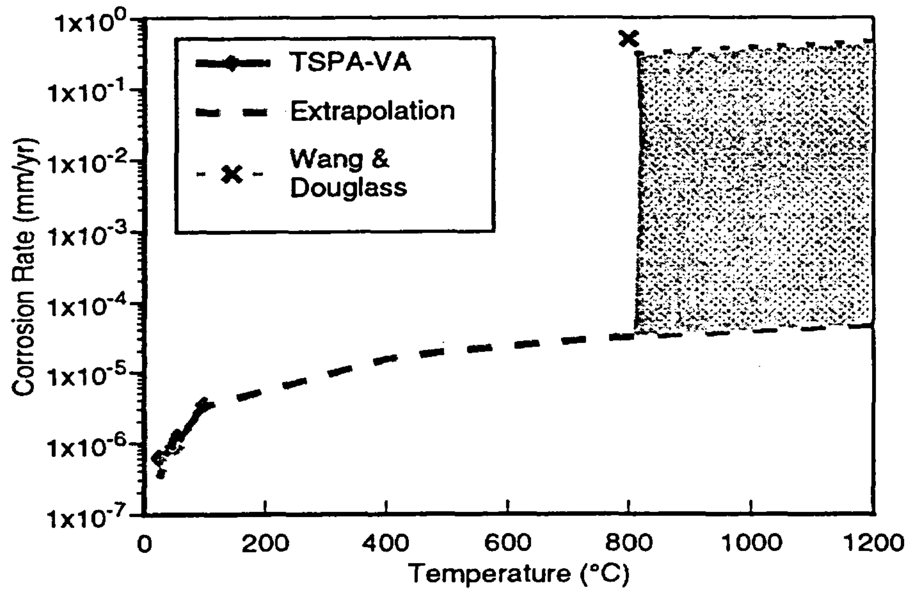


Source Term (Continued)

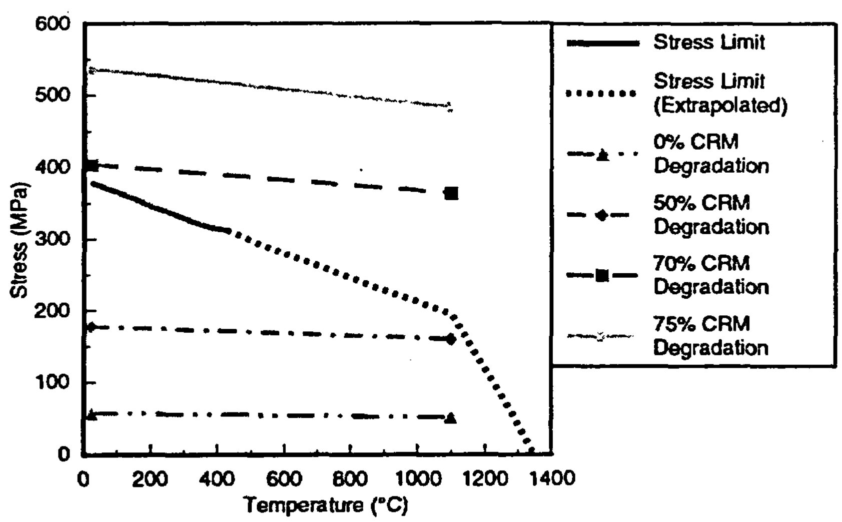
Waste-Package Breach

- Magmatic intrusion is extremely hostile environment
  - Temperature: 1000°C – 1200°C
  - Corrosive gasses present (SO_2, H_2O, CO_2, HF)
- CAM on waste package does not survive
- CRM (C-22) is quite resistant to this environment
  - eruption duration (5 days – 40 days) is insufficient to corrode full-thickness CRM
  - Waste package is breached if it has previously corroded to ~50% thickness
- CRM failure mode is corrosion and high-temperature deformation

CRM Corrosion Rate



CRM Deformation



Source Term (Continued)

Waste-Particle Ejection and Entrainment

- Waste particles have density of ~11 g/cm^3
  - ash density is 0.8 – 2.65 g/cm^3
- Impinging ash requires sufficient momentum (mass and velocity) to remove and carry waste
  - relative sizes of ash and waste – 1:1 or 2:1
- Heavy waste particles can settle in ascending ash and not reach surface

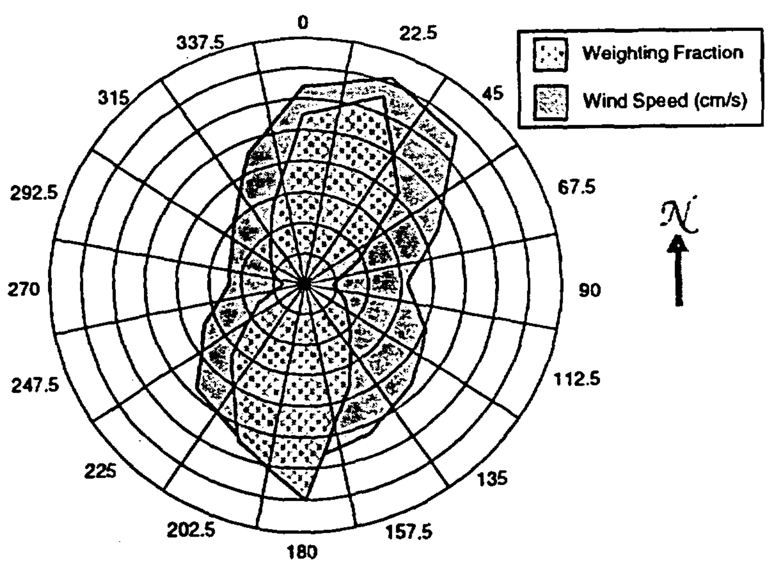
Results of Source-Term Modeling

- Of 300 realizations, 17 produced radionuclides at surface for input to ASHPLUME (5.7%)
  - some realizations were eliminated by dikes not intersecting repository, or no vents occurring inside repository
  - almost all realizations where liquid magma interacted with waste were eliminated
    - *insufficient ascent velocity*
  - waste package was breached only if time of occurrence of event was later than about 400,000 years, which eliminated a few realizations
    - range of times for 50% CRM reduction is 400,000 – 1,000,000 years
  - many realizations were eliminated because ash particle sizes were too small to eject waste

ASHPLUME Analyses

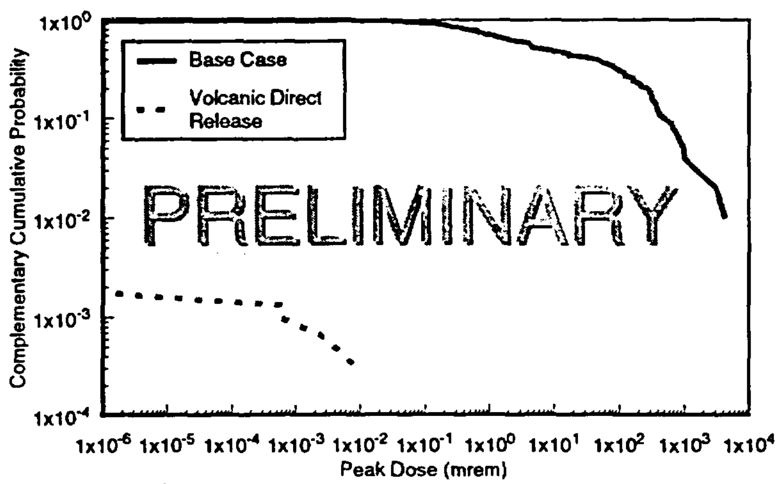
- Code was run in "deterministic" mode using stochastically developed source term
- Wind direction and speed was stochastically selected for the 17 runs
  - 9 of the 17 runs had wind blowing northerly, away from main dose receptor point

Wind Rose



Dose Calculations

- Time of occurrence used to calculate radionuclide inventory
- BDCFs for 39 radionuclides applied to ASHPLUME surficial concentration at receptor point (20 km south of vent)

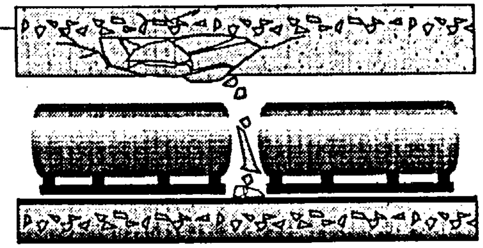


Seismic Activity

- Primary disruption is expected to be from rockfall
- Water-table rise, seismic pumping, refocusing of UZ flow are short-term or low-impact events
- Rockfall can occur from thermo-mechanical or seismic effects
  - seismic is lower probability than thermo-mechanical

Rockfall Scenario

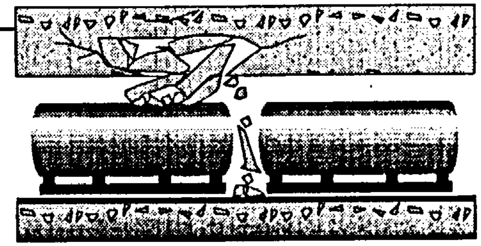
Selsmic events or thermo-mechanical effects cause rocks to fall from drift ceiling.



No → STOP *No performance assessment consequence. End Scenario.*

Yes ↓

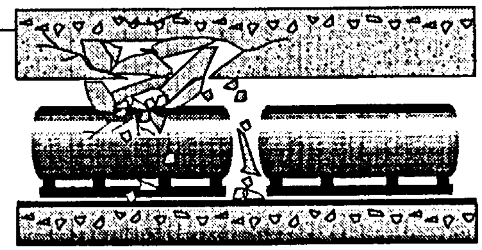
Falling rocks strike waste packages.



No → STOP *No performance assessment consequence. .*

Yes ↓

Rock ruptures waste package.

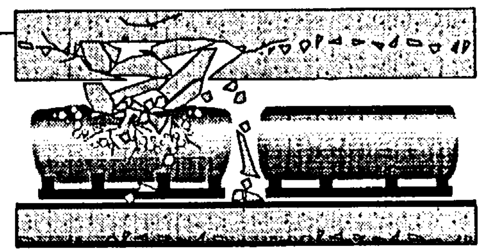


No → **Rock damages waste package wall.**

No → *Performance assessment consequence not modeled here.*

Yes ↓

Waste package corrosion increases at site of damage.



No → *Performance assessment consequence modeled in base case.*

Yes ↓ *Yes* ↓

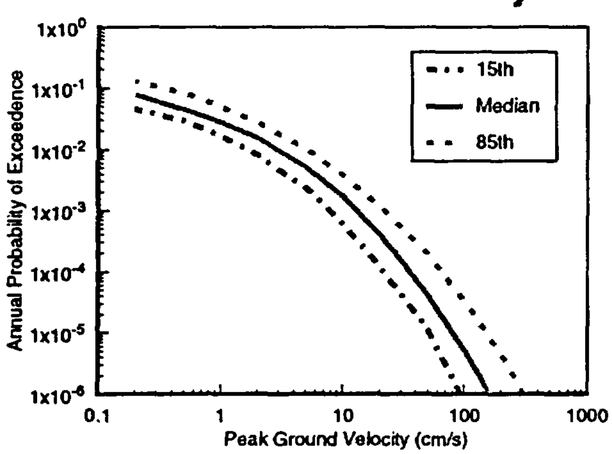
Waste is more accessible to groundwater.
Enhanced source term for groundwater radionuclide transport.
Performance Assessment consequence is measured by dose at receptor site.

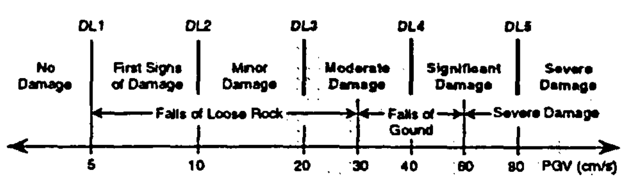
snl/trw abq 04.eps

Rockfall Analysis

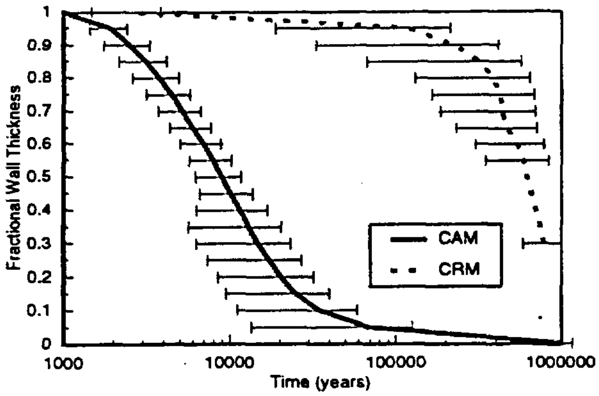
- Initiated by seismic event
  - Peak ground velocity determines extent of rockfall
    - more competent rock requires greater seismic disruption
- Damage caused by rockfall on waste package depends on impact
  - minimum rock mass that can breach or dent waste package
  - waste-package corrosion reduces mass of critical rock
- Distribution of potential rock sizes determines if one is available to do damage

Peak Ground Velocity and Damage Levels

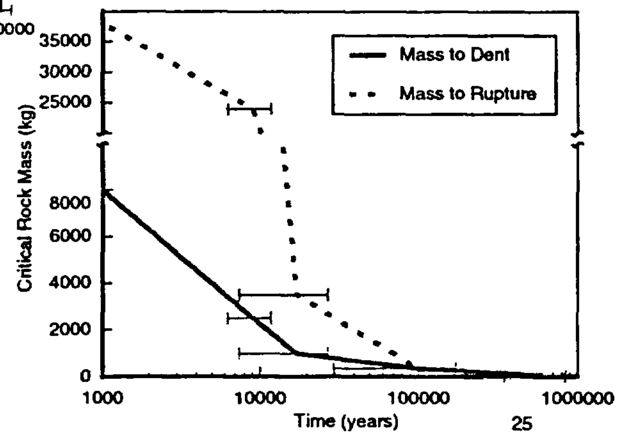




Critical Rock Masses and WP Corrosion

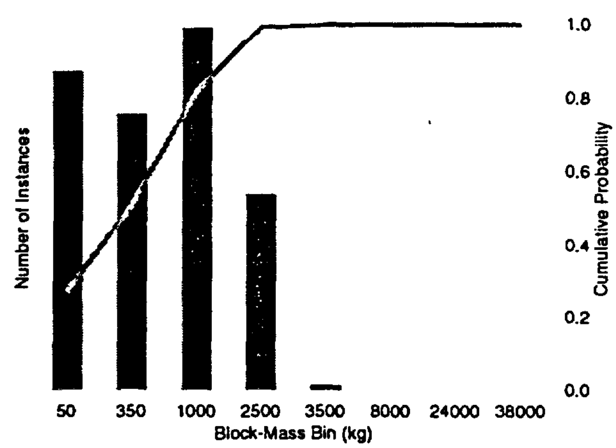


CRM corrosion rate for dripping conditions



Block-Size Distribution

- Derived from ESF joint-frequency study



Description of Rockfall Analysis

- Time of occurrence -> PGV -> rockfall characteristics
  - the greater PGV, the larger rocks that fall
- Time of occurrence -> extent of waste package degradation
  - determines minimum size rock that can damage waste package
- Sampling from rock-size distribution determines if rock does damage
  - if no breach, size of rock determines acceleration of localized corrosion
- WAPDEG calculations provide source term to RIP

Preliminary Results of Rockfall Modeling

- Rockfall analyses stratified by hazard level
- No rockfall failures in less than 10,000 years
  - predicted PGV is small
  - waste-package walls are thick
- Overall, ~12% of rockfall events cause failure in 1,000,000 years

Hazard Level	Average Time of Occurrence (years)	Average PGV (cm/s)	Fraction of Packages Breached*	Fraction of Packages Damaged
> E-3	560	9.9	0.0	0.0
E-3 ~ E-4	5500	28.0	0.0	0.001
E-4 ~ E-5	57600	67.4	0.167	0.013
E-5 ~ E-6	533800	135.7	0.310	0.013

* Includes the probability that falling rock hits a package, and doesn't fall between packages

YUCCA
MOUNTAIN
PROJECT

Summary and Discussion

Presented to
NWTRB
Panel on Performance Assessment: TSPA-VA
Albuquerque, New Mexico

Presented by:
Holly A. Dockery
Deputy Manager, Performance Assessment Operations
CRWMS M&O/Sandia National Laboratories
Albuquerque, New Mexico

April 24, 1998

Review of Results - Dose Values

- 10,000 yrs
  - 5% - 0 mrem/yr
  - "expected value" - 0.04 mrem/yr
  - 95% - 0.85 mrem/yr
- 100,000 yrs
  - 5% - 0 mrem/yr
  - "expected value" - 5.3 mrem/yr
  - 95% - 210 mrem/yr
- 1,000,000 yrs
  - 5% - 0.071 mrem/yr
  - "expected value" - 300 mrem/yr
  - 95% - 1000 mrem/yr

Review of Results - Uncertainty Analyses

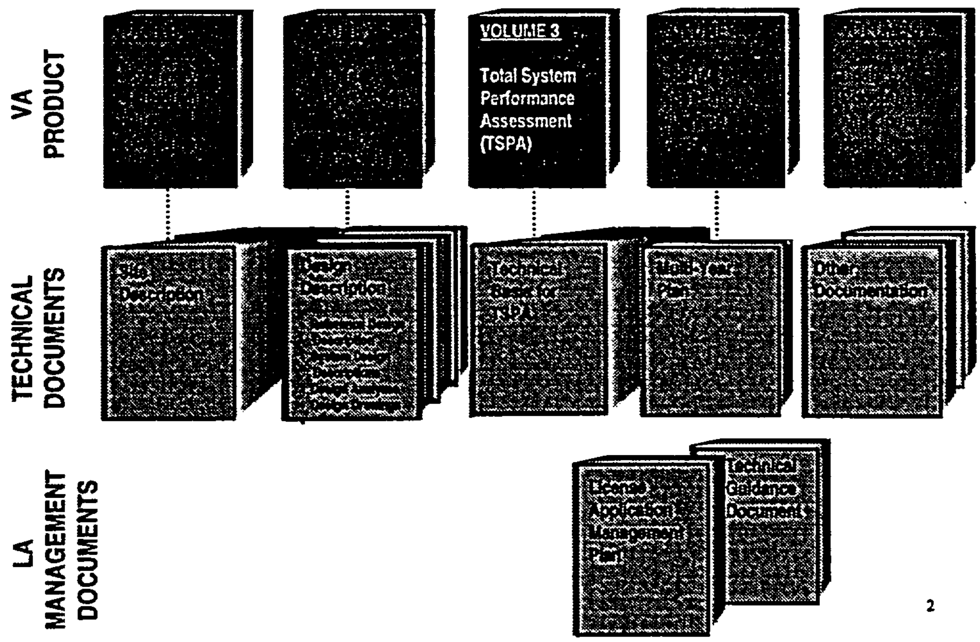
The five most sensitive parameters in all of the regression analyses (10,000, 100,000, and 1,000,000 year runs):

- seepage fraction
- CRM corrosion rate
- number of juvenile failures
- saturated zone dilution
- percolation flux

Remaining Activities

- Complete TSPA-VA documentation for internal review.
  - Respond to review comments and revise Chapter 3 of the VA document.
  - Ensure consistency with LA Plan portion of VA.
- Complete documentation of individual components for Technical Bases Report.
  - Respond to review comments and revise TBR
- Initiate review of the TSPA-VA with the PA Peer Review Panel.
- Develop a plan to address QA issues.
- Work on modifying TSPA-VA documentation for public forums.
- Begin planning for LA abstraction/testing activities.

PROGRAM DOCUMENTATION



2

Outline of TSPA-VA Volume

Overview

1. Introduction/objectives
2. Approach/methodology
   - definition of base case
3. Results
   - base case deterministic (single point estimate) analyses
   - uncertainty analyses of base case
   - sensitivity analyses
     - alternative models
     - disruptive features, events and processes
     - design options

Outline of TSPA-VA Volume (continued)

4. Component models of TSPA
   - unsaturated zone flow
   - thermal hydrology
   - near-field geochemical environment
   - waste package degradation
   - waste form alteration
   - radionuclide mobilization and EBS transport
   - unsaturated zone transport
   - saturated zone flow and transport
   - biosphere
   - disruptive features, events and processes
5. Summary and Discussion
   - information needs for TSPA-LA

Outline of TSPA-VA Technical Basis Report

1.0 TSPA-VA Introduction

2.0 - 11.0

x.1 Component* Introduction

(Overview, Previous TSPA Modeling, Synopsis of Current Approach, Chapter Organization, Data Quality and Traceability)

x.2 Component Characterization

x.2.1 Description of the Component System

x.2.2 Site Characterization Models

x.2.3 Conceptual Models

(Issues from Abstraction/Testing Workshops, Expert Elicitation, Base-Case Conceptual Model, Alternative Conceptual Models)

x.3 Analysis Approach for TSPA Analyses

**components are UZ Flow, Thermal hydrology, Near-Field Geochemical Environment, Waste Package Degradation, Waste Form Alteration, Radionuclide Mobilization and EBS Transport, UZ Transport, SZ Transport, Biosphere, and Disruptive FEPs)*

Outline of TSPA-VA Technical Basis Report (continued)

- x.4 Component Base Case
  - x.4.1 Description of the Base Case
  - x.4.2 Development of Parameter Distributions and Uncertainty
  - x.4.3 Analyses
  - x.4.4 Results
  - x.4.5 Interpretation
  - x.4.6 Guidance for Sensitivity Studies
- x.5 Sensitivity Studies
- x.6 Summary and Recommendations

  (Summary of Methods and Results, Implications for Repository Performance, Guidance for License Application)
- x.7 References

12.0 Synthesis of Abstracted Models into the TSPA Model

13.0 Summary of Additional Model Development, Testing, Abstraction and Documentation Required for TSPA-LA

Work Underway to Implement a QA Program for PA

- A plan has been initiated to allow for a phased approach to implementing a QA program for PA.
- The documentation of requirements that will govern QA for PA activities has completed formal review.
- Two "vertical slice" reviews have been completed to identify weaknesses and gaps in the traceability and transparency of PA documentation.
  - a "lessons learned" meeting was held in April to brief to the PA team on the findings of the reviews.
- Software qualification and configuration management activities have been initiated and several PA codes have been placed under configuration management.
- Documentation of the current TSPA QA implementation effort will be completed in summer 1998.

How Well Did We Address the Questions to be Asked of TSPA-VA?

Is the TSPA an effective tool for assessing the safety of the potential repository system?

Does the TSPA generate confidence?

How well did we do in our presentations in conveying our assumptions, information, and results?

What specific suggestions does the Board have for improving the TSPA process and presentation?

NYE COUNTY, NEVADA
DEPARTMENT OF NATURAL RESOURCES & FEDERAL FACILITIES
41 North Highway 160 #8, Pahrump, Nevada 89048
(702) 727-7727 - (702) 727-7919 Fax

MEMORANDUM

TO	**Neil Coleman - USNRC**
email	NMC@NRC.GOV
FROM	Mary Long
DATE	May 4, 1998
SUBJECT	References

cc:
OF PAGES: 1

Nick Stellavato asked me to email the following information to you. Please let me know if you have any questions.

FROM: GEOSCIENCES MANAGEMENT INSTITUTE, INC.

References: (partial or full support from Nye County N.W.R.P.O.)

Morgenstein, M.E., Wickert, C.L., and A. Barkatt (to be submitted) Considerations of Hydration-Rind Dating of Glass Artifacts: Alteration Morpho;ogies and Experimental Evidence of Hydrogeochemical Soil-Zone Pore Water Control. (To be submitted to an archeological journal spring/summer 1998.)

Shettel, D.L. (1995) Actinide Source Term Predictions for Spent Fuel at Yucca Mountain: Proc. Sixth Annual International High-Level Radioactive Waste Management Conf., Las Vegas, NV, pp. 609-611.

Shettel, D.L., Morgenstein, M.E., Krinsley, D., and M. Zreda (1998) Geochemistry and Petrography of Samples from Borehole UE25-ONC#1 at Yucca Mountain, Nevada: Proc. Ninth Annual International High-Level Radioactive Waste Management Conf., May 11-14, 1998, Las Vegas, NV. (Full support)

Sun, Zhuang (1997) Post-Closure Silica Transport in the Proposed High Level Radioactive Waste Repository at Yucca Mountain, Nevada. M.Sc. Thesis at Virginia Polytechnic Institute and State University, Blacksburg, Virginia. Full support provided to this student under Dr. J.D. Rimstidt. To be submitted to Applied Geochemistry.

FROM: MULTIMEDIA ENVIRONMENTAL TECHNOLOGY (MET)

Reports Prepared by MET for Nye County N.W.R.P.O.

"Interim Report on Results of Instrumentation And Monitoring of UE-25 ONC#1 and USW NRG-4 Boreholes, Yucca Mountain, Nevada" July, 1995.

"Moisture Removal from the Repository by Ventilation and Impacts on Design", International High-Level Radioactive Waste Conference, May 1996.

"Simulations and Observations of ESF Tunnel Effects on Barometric Conditions" May 1996.

"Annual Report on Results of Instrumentation and Monitoring of UE-25 ONC#1 and USW NRG-4 Boreholes, Yucca Mountain, Nevada" July 1996.

"Annual Report of the Nye County Nuclear Waste Repository Project Office Independent Scientific Investigations Program" October 1996.

"Results of First Gas Sampling from ONC#1. October 1996" February 1997.

"Summary of Annual Report May 1996 - April 1997 Nye County Nuclear Waste Repository Project Office Independent Scientific Investigations Program" May 1997.

"Results of Gas Sampling from ONC#1. June 1997 November 1997.

"Generating Electricity, Keeping Repository Cool, Dry, and Reducing Acreage Requirement", High-Level Radioactive Waste Management Conference, May 1998

"Environmental Gases, Permeability, and Thermal Conductivity Tests at Borehole ONC#1". High-Level Radioactive Waste Management Conference, May 1998.