ENCLOSURE

SUMMARY OF NRC/DOE TECHNICAL EXCHANGE ON THE RESULTS OF THE NRC AUDIT REVIEW OF DOE'S TSPA-95

May 22-23, 1996
U.S. Department of Energy
Bank of America Building
101 Convention Center Drive
Las Vegas, Nevada 89109

On May 22-23, 1996, staff from the U.S. Nuclear Regulatory Commission and the U.S. Department of Energy (DOE) conducted a technical exchange to discuss the results of the recently completed NRC staff audit review of DOE's *1995 Total System Performance Assessment* for a proposed repository at Yucca Mountain, Nevada (hereafter referred to as "TSPA-95"[1]). Representatives from the State of Nevada, affected units of local government, the U.S. Nuclear Waste Technical Review Board (NWTRB), the Advisory Committee on Nuclear Waste, the Electric Power Research Institute, and DOE program participants also attended the technical exchange. The agenda is Attachment 1; Attachment 2 is the list of attendees.

On May 22, 1996, both the NRC staff and its technical assistance contractor — the Center for Nuclear Waste Regulatory Analyses (CNWRA) — made presentations. The first series of presentations consisted of opening remarks, made by the NRC staff, in which the goals and objectives of the audit review were summarized (see Attachments 3 and 4). The NRC staff noted that it would be formally transmitting the results of its audit review to DOE, later this summer. (The staff also noted that, at the end of the calendar year, it intends to provide DOE with additional, detailed comments.) The State of Nevada and affected units of local government also made some opening remarks.

The staff also noted that one of its objectives in the audit review was to relate concerns within focused technical areas to DOE's *Waste Containment and Isolation Strategy*. At the staff's request, DOE updated the attendees on the status of the evolving strategy. DOE indicated that the next iteration of its *Waste Containment and Isolation Strategy* should be available in the June 1996 time frame. It was also noted by DOE that a detailed implementation plan for the strategy was in

1 TRW Environmental Safety Systems Inc., "Total System Performance Assessment — 1995: An Evaluation of the Potential Yucca Mountain Repository," Las Vegas, Nevada, Document No. B00000000-01717-2200-00136 (Rev. 01), November 1995. [Prepared for the U.S. Department of Energy/Office of Civilian Radioactive Waste Management.]

preparation and DOE indicated that this plan is tentatively scheduled to be available sometime in December 1996.

The second series of presentations on May 22, 1996, consisted of summaries of the focused review audit results of *TSPA-95* that were performed by the NRC and the CNWRA staffs. The NRC audit review, using the key technical issue team concept, focused on the technical areas considered important to performance: repository temperature and relative humidity; waste package container life and source term; ground-water infiltration and deep percolation; radionuclide dilution; and TSPA abstraction (see Attachments 5-9). Each presentation was followed by discussion and some questions. Those questions and talking points, determined to require more focused discussion (see Attachment 10), were deferred to the respective Working Groups, to be convened on the second day of the technical exchange.

On May 23, 1996, the second day of the technical exchange began with an overview of a ^{237}Np dose calculation performed by the NRC staff (see Attachment 11). This calculation is similar to calculations performed in *TSPA-95* and is an example of staff attempts to better understand how DOE performed comparable calculations. After the dose calculation discussions, the staff provided its suggestions for the documentation of DOE's *Waste Containment and Isolation Strategy* (see Attachment 12).

The third agenda item on the second day of the technical exchange was the two Working Group sessions that provided follow-up discussion to and clarification of the previous day's presentations (e.g., Attachment 10). The follow-up and clarification that were provided are summarized in Attachment 13.

The State of Nevada, affected units of local government, and the NWTRB were invited to present their respective comments, if any, at the end of the technical exchange. The NWTRB declined to comment. The State of Nevada's observations and comments are summarized in Attachment 14. Affected units of local government made a few comments, as well.

At this technical exchange, the staff and DOE introduced a new meeting format that included the following elements: formal presentations in which questions were raised; "break-out" sessions in which smaller working groups discussed specific questions and technical issues; and a closing summary session in which the results of the break-out sessions were reported. The consensus among meeting participants was that this format successfully facilitated focused discussion of key issues.

At the end of the technical exchange, it was agreed that the respective staffs might benefit from more focused interactions in the future. For example, a "vertical-slice" type of meeting, including field observations, process modeling, and performance assessment abstractions, related to radionuclide migration, might be an appropriate meeting topic. Other topics for subsequent meetings were also proposed. It was agreed that such meetings should include those staff who conduct the site investigations, as well as those staff who are involved with performance assessment modeling.

Michael P. Lee
Performance Assessment and
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Division of Waste Management
Office of Nuclear Material Safety
and Safeguards
U.S. Nuclear Regulatory Commission

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Regulatory Integration Division
Office of Program Management and Integration
Office of Civilian Radioactive
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ATTACHMENT 1

AGENDA
NRC/DOE Technical Exchange on the Audit Review of TSPA-95

Bank of America Building
Convention Center Drive
Las Vegas, Nevada

May 22, 1996

Agenda Item	*Discussion Lead(s)*
Opening Remarks	*NRC, DOE, State, and Local Govt's*
Temperature and Relative Humidity	*NRC/CNWRA*
Container Life and Source Term	*NRC/CNWRA*
Infiltration and Deep Percolation	*NRC/CNWRA*
Dilution	*NRC/CNWRA*
TSPA Abstraction	*NRC/CNWRA*

May 23, 1996

^{237}Np Dose Comments	*NRC*
NRC Comments on DOE's Waste Isolation Strategy	*NRC*
Working Group 1 — Container Life and Source Term/Thermal Effect	*NRC/DOE*
Working Group 2 — Infiltration and Deep Percolation/Dilution/TSPA	*NRC/DOE*
Working Group Summaries and Round Table Discussion	*NRC/DOE*
Closing Remarks	*All*

Attendees at the May 22-23, 1996, NRC/DOE Technical Exchange on the Audit Review of TSPA-95

Affected-Units-of-Local-Government
M. Murphy/Nye Co. P. Montazer/Nye Co. E. Tiesenhausen/Clark Co.

Advisory Committee on Nuclear Waste
A. Campbell

Center for Nuclear Waste Regulatory Analyses
R. Baca R. Manteufel N. Sridar G. Stirewalt S. Stothoff G. Wittmeyer

DOE Management & Operating Contractor/Intera
B. Andrews J. Atkins T. Crump B. Dunlap S. Echols A. Haghi
J. Lee B. Mann S. Mistra J. McNeish D. Sassani E. Siegman
D. Sevougian D. Stahl J. York

Electric Power Research Institute
J. Kessler

Lawrence Berkeley National Laboratory
B. Bodvarssan

Lawrence Livermore National Laboratory
J. Blink B. Halsey

Risk Engineering Inc.
R. McGuire

Sandia National Laboratories
S. Altman W. Arnold H. Dockery N. Francis J. Gauthier C. Ho
M. Wilson

State of Nevada
C. Johnson S. Frishman L. Lehman M. Mifflin J. Treichel

U.S. Department of Energy
P. Bunton T. Bjerstedt N. Chappel S. Dana B. Fish A. Gil
S. Hanauer D. Haught B. Levich B. Mulehopadhyay
R. Musick R. Patterson J. Rosenthal E. Smistad T. Sullivan A. Van Luik

U.S. Geological Survey
A. Flint L. Flint R. Wallace

U.S. Nuclear Regulatory Commission
T. Ahn M. Bell W. Belke K. Chang R. Codell N. Eisenberg
J. Glenn M. Lee K. McConnell J. Pohle R. Wescott

U.S. Nuclear Waste Technical Review Board
V. Palciauskas L. Reiter

University of Texas @ El Paso
J. Walton

ATTACHMENT 3A

INTRODUCTION

AUDIT REVIEW OF TSPA 95

NRC/DOE TECHNICAL EXCHANGE ON TSPA

Las Vegas, Nevada
May 22-23, 1996

Rex Wescott, NRC
Robert Baca, CNWRA

OVERALL REVIEW SCHEDULE AND STRATEGY

AUDIT REVIEW OF TSPA 95

- Completed at end of April 1996
- Five focused areas evaluated
- Additional potential areas for focused review identified

DETAILED REVIEW OF TSPA 95 AND SUPPORTING DOCUMENTS

- To be completed in December 1996
- Detailed analyses expected in other areas significant to performance
- Significance to performance to be evaluated quantitatively

OBJECTIVES OF AUDIT REVIEW

- **Identify areas of focus that are common to TSPA 95 and to the technical assessment work completed or being performed under the NRC/CNWRA KTIs.**

- **Within the focused areas, identify significant differences between the NRC/CNWRA approaches to performance assessment and those presented in TSPA 95.**

OBJECTIVES OF AUDIT REVIEW (contd.)

- **Develop positions and/or concerns in a quantitative manner such that quantitative effects on performance can be evaluated.**

- **Identify additional areas to be evaluated in detailed review.**

OBJECTIVES OF TECHNICAL EXCHANGE

- Provide early feedback to DOE and other interested parties in regard to our review methodology (detailed evaluation and independent technical assessment) applied to a few selected areas.

- Transmit our positions/concerns to DOE in a manner that will allow incorporation and/or evaluation in the TSPA or auxiliary analysis. For example, as an alternative conceptual (or abstracted) model, sampled data distribution, or etc.

TECHNICAL EXCHANGE (contd.)

- Provide concerns in the focused areas which are likely to have asignificant effect on total system performance.
- Provide for working groups on related areas where ideas and explanations can be exchanged.
- Suggest specific subjects for further discussion.
- Relate concerns within focused areas to DOE Waste Isolation Strategy

NRC/CNWRA KEY TECHNICAL ISSUES

Support Revision of EPA Standard/ NRC Rulemaking

Total System Performance Assessment and Technical Integration

Igneous Activity

Unsaturated and Saturated Flow Under Isothermal Conditions

Thermal Effects on Flow

Container Life and Source Term

Structural Deformation and Seismicity

Evolution of Near-Field Environment

Radionuclide Transport

Repository Design and Thermal-Mechanical Effects

FOCUSED AREAS AND ASSOCIATED KTIs

Focused Area:	**Temperature and Relative Humidity**
Associated KTI:	**Thermal Effects on Flow**
Focused Area:	**Container Degradation Modes**
Associated KTI:	**Container Life and Source Term**
Focused Area:	**Infiltration and Deep Percolation**
Associated KTI:	**Unsaturated and Saturated Flow Under Isothermal Conditions**

Focused Area: Dilution
Associated KTI: Unsaturated and Saturated Flow Under Isothermal Conditions

Focused Area: TSPA Abstraction
Associated KTI: Total System Performance Assessment and Integration

WCIS HYPOTHESES ASSOCIATED WITH FOCUSED AREAS IN AUDIT REVIEW

SEEPAGE:

- Percolation flux at repository depth is small due to evaporation and diversion. (2)

CONTAINMENT:

- Heat produced by emplacement waste will reduce relative humidity in the vicinity of waste packages; evaporation in a backfill could further reduce humidity. (5)

- Corrosion rates are negligible at low relative humidity. (6)

- Double-walled waste packages will significantly increase containment times. (7)

DILUTION:

- Flow in the saturated zone is much greater than the flow contacting the waste. (9)

- Water percolating down through Yucca Mountain to the water table mixes strongly with the flow in the aquifer. (10)

ADDITIONAL HYPOTHESES EXPECTED TO BE ADDRESSED IN DETAILED REVIEW

SEEPAGE:

- Fracture flow is limited at repository depth. (1)

- Capillary forces limit seepage into the emplacement drifts to a small fraction of the incident percolation flux. (3)

- Bounds can be placed on thermally-induced changes to seepage rate. (4)

TRANSPORT:

- Engineered barriers, such as backfill, have sufficient radionuclide depletion and dispersion potential to reduce concentrations of key actinides, including neptunium. (8)

DISRUPTIVE PROCESSES AND EVENTS:

- Movement on faults will be insufficient to bring waste to the surface in the next million years or to impact containment in the next few thousand years. (11)

- **Ground shaking in the repository will be insignificant for tens of thousands of years. (12)**

- **Volcanic events within the controlled area will be rare and the consequences of volcanism will be limited in the next million years. (13)**

ADDITIONAL AREAS BEING CONSIDERED IN DETAILED REVIEW

The extent to which the following issues will be pursued will depend upon their significance to total system performance and/or the DOE Waste Containment and Isolation Strategy.

KTI: IGNEOUS ACTIVITY

- **Effect of direct disruption of the repository on total system performance including establishment of a lower bound probability and consequence analyses.**

KTI: STRUCTURAL DEFORMATION AND SEISMICITY

- Effects of faulting and seismicity on total system performance assessment (possibly including repeated seismicity)

KTI: EVOLUTION OF NEAR-FIELD ENVIRONMENT

- Near-field chemical evolution and with regard to effects on radionuclide solubilities and waste package corrosion.

ADDITIONAL AREAS (cont.)

KTI: RADIONUCLIDE TRANSPORT

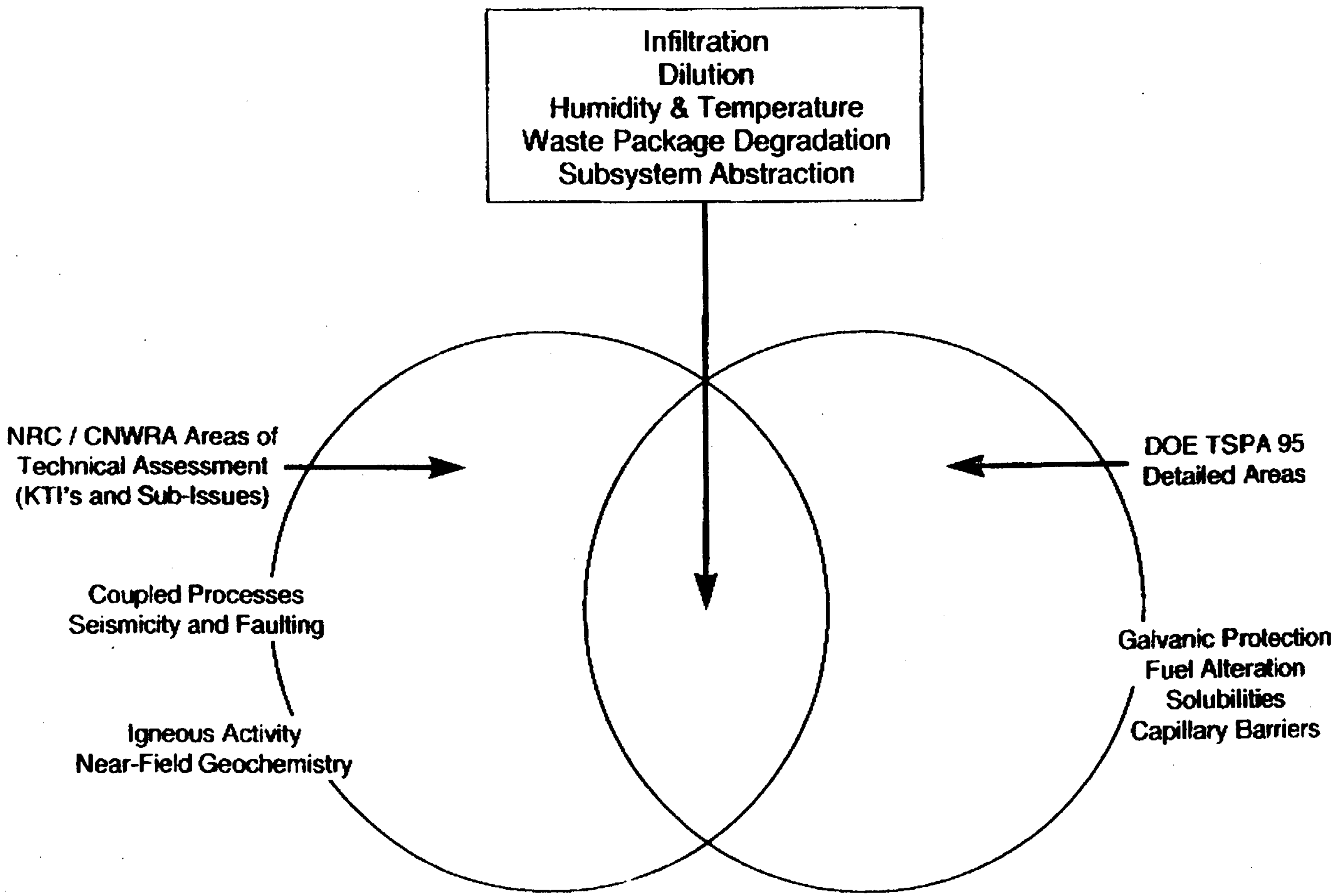
- Distribution coefficients
  (including use, testing methods, and system chemistry

KTI: REPOSITORY DESIGN AND THERMAL-MECHANICAL EFFECTS

- Effects of thermal-mechanical coupling on hydraulic conductivity.

- Effects of thermal stresses on drift stability.

Focused Areas For Audit Review



OVERALL REVIEW SCHEDULE AND STRATEGY

AUDIT REVIEW OF TSPA 95

- Completed at end of April 1996
- Five focused areas of concern
- General comments from other areas

DETAILED REVIEW OF TSPA 95 AND SUPPORTING DOCUMENTS -

- To be completed in December 1996
- Focused areas expected in all Key Technical Issues
- Effects of alternative conceptual models on total system performance to be included

OBJECTIVES OF AUDIT REVIEW

- Identify areas of focus that are common to TSPA 95 and to the technical assessment work completed or being performed under the NRC/CNWRA KTIs.

- Provide comments in areas other than those identified as focused areas. These comments are intended to indicate that improvement in identified areas is still required.

- Within the focused areas, identify significant differences between the NRC/CNWRA approaches to performance assessment and those presented in TSPA 95.

- Develop positions and/or concerns in a quantitative manner such that quantitative effects on performance can be evaluated.

OBJECTIVES OF TECHNICAL EXCHANGE

- Provide early feedback to DOE and other interested parties in regard to our review methodology (detailed evaluation and independent technical assessment) and results thus far.
- Transmit our positions/concerns to DOE in a manner that will allow incorporation in a TSPA. For example, as an alternative conceptual (or abstracted) model, sampled data distribution, or etc.
- Provide concerns in the focused areas to concerns which are likely to have a significant effect on total system performance.
- Provide for working groups on related areas where ideas and explanations can be exchanged.
- Suggest specific subjects for further discussion in teleconferences or Appendix 7 visits.
- Relate concerns within focused areas to DOE Waste Isolation Strategy

FOCUSED AREAS AND ASSOCIATED KTIs

Focused Area:	Temperature and Relative Humidity
Associated KTI:	Thermal Effects on Flow
Focused Area:	Container Degradation Modes
Associated KTI:	Container life and Source Term
Focused Area:	Infiltration and Deep Percolation
Associated KTI:	Unsaturated and Saturated Flow Under Isothermal Conditions
Focused Area:	Dilution
Associated KTI:	Unsaturated and Saturated Flow Under Isothermal Conditions
Focused Area:	TSPA Abstraction
Associated KTI:	Total System performance Assessment and Integration

OTHER CONTRIBUTING KTIs

Radionuclide Transport

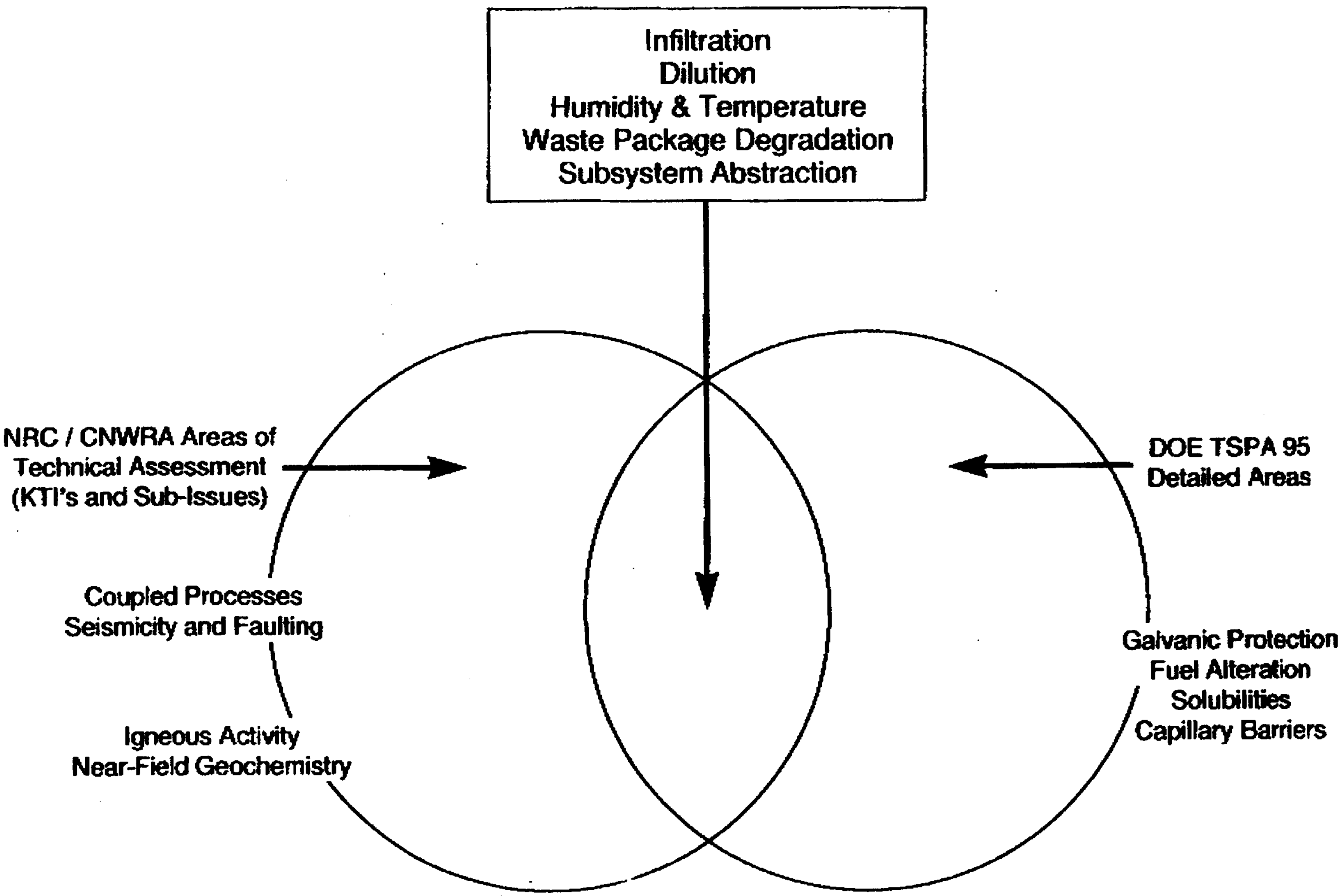
Evolution of Near-Field Environment

Repository Design and Thermal-Mechanical Effects

Structural Deformation and Seismicity

Igneous Activity

Focused Areas For Audit Review



WCIS HYPOTHESES ASSOCIATED WITH FOCUSED AREAS IN AUDIT REVIEW

SEEPAGE:

- Percolation flux at repository depth is small due to evaporation and diversion. (2)

CONTAINMENT:

- Heat produced by emplacement waste will reduce relative humidity in the vicinity of waste packages; evaporation in a backfill could further reduce humidity. (5)
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DILUTION:

- Flow in the saturated zone is much greater than the flow contacting the waste. (9)
- Water percolating down through Yucca Mountain to the water table mixes strongly with the flow in the aquifer. (10)

ADDITIONAL WCIS HYPOTHESES LIKELY TO BE ADDRESSED IN DETAILED REVIEW

SEEPAGE:

- Fracture flow is limited at repository depth. (1)
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- Ground Shaking in the repository will be insignificant for tens of thousands of years.
- Volcanic events within the controlled area will be rare and the consequences of volcanism will be limited in the next million years.

Opening Remarks for Technical Exchange on PA *

May 22-23, 1996

Good morning.

The NRC staff welcomes this opportunity to discuss TSPA-95 with the DOE staff and contractors, representatives of the State of Nevada, and other interested parties.

The NRC staff views performance assessment as an essential element in DOE's demonstration of compliance with applicable regulations, which is the most important element in DOE's demonstration of the safety of the repository. The PA staff at NRC and the DOE have delineated a common vision of PA and the essential role it plays in the HLW program. PA is a hierarchical methodology that incorporates information from site characterization, design, and detailed modeling activities into an overall approach to safety. This is exemplified by the "pyramid" diagrams that have been displayed in the past. The NRC staff notes that the DOE has, in recent times, bolstered the role of PA in the program.

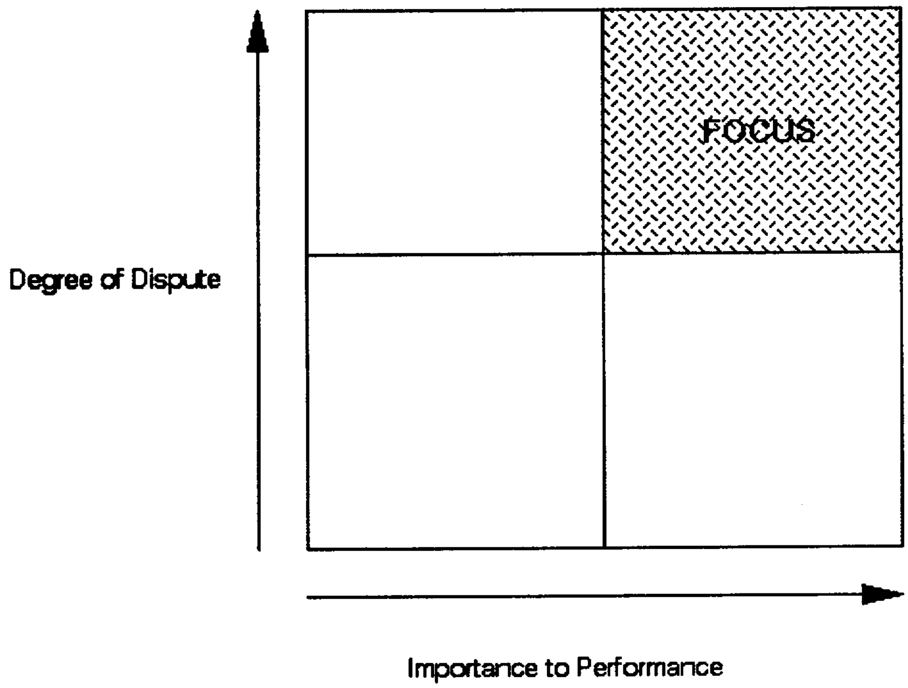
A very important aspect of the role of PA is its contribution to evaluating the importance of various components or aspects of the repository system and the issues, studies, models, and programs attached to them. As the HLW program has matured, it has become appropriate to focus on those issues most important to waste isolation. The NRC staff has recognized this by adopting a programmatic approach centered on a set of 10 Key Technical Issues. During any given time period, the programmatic activities are planned to address one or more "Vertical Slice(s)" in selected KTI's. Each vertical slice is a focussed activity addressing an aspect of the KTI from top to bottom; e.g. the probability of volcanism would be addressed from the gathering of field data, the synthesis of this data into a probabilistic model, and the use of such a model in a total system performance assessment. There is an emphasis on resolution of issues with the DOE.

Although the KTI's and vertical slices respond to budgetary limitations, this focus on issues important to safety is believed to enhance the overall effectiveness of NRC's regulatory efforts. By focussing on the most important issues, rather than all potential areas of disagreement with DOE, NRC staff activities have a higher expectation of benefit. The attached chart shows how we desire to focus on areas that: (1) have a known importance to repository performance and (2) have a significant degree of dispute.

One final thought, importance to performance is may be thought of in absolute terms, but it is usually more profitable to think of it in terms of the **demonstration** of safety or compliance. The importance to a demonstrationis dependent on the strategy adopted

* Presented by Norman Eisenberg, NRC/DWM

by the licensee. For example, DOE has the flexibility of placing emphasis on dilution, hence the flow system in the saturated zone will become very important. Alternatively, DOE could place heavy reliance on sorption, placing great importance on the geochemistry in the unsaturated or saturated zone. For this reason the staff has placed some emphasis on reviewing TSPA-95 through the lens of the DOE Waste Isolation Strategy.


FOCUS
Degree of Dispute
Importance to Performance

AREA OF CONCERN: CALCULATION OF TEMPERATURE AND RELATIVE HUMIDITY IN TSPA-95

Collaborators
R. Green, G. Rice, G. Ofoegbu

R. Wescott, J. Pohle (NRC)

Center for Nuclear Waste Regulatory Analyses

Presented by
Randy Manteufel

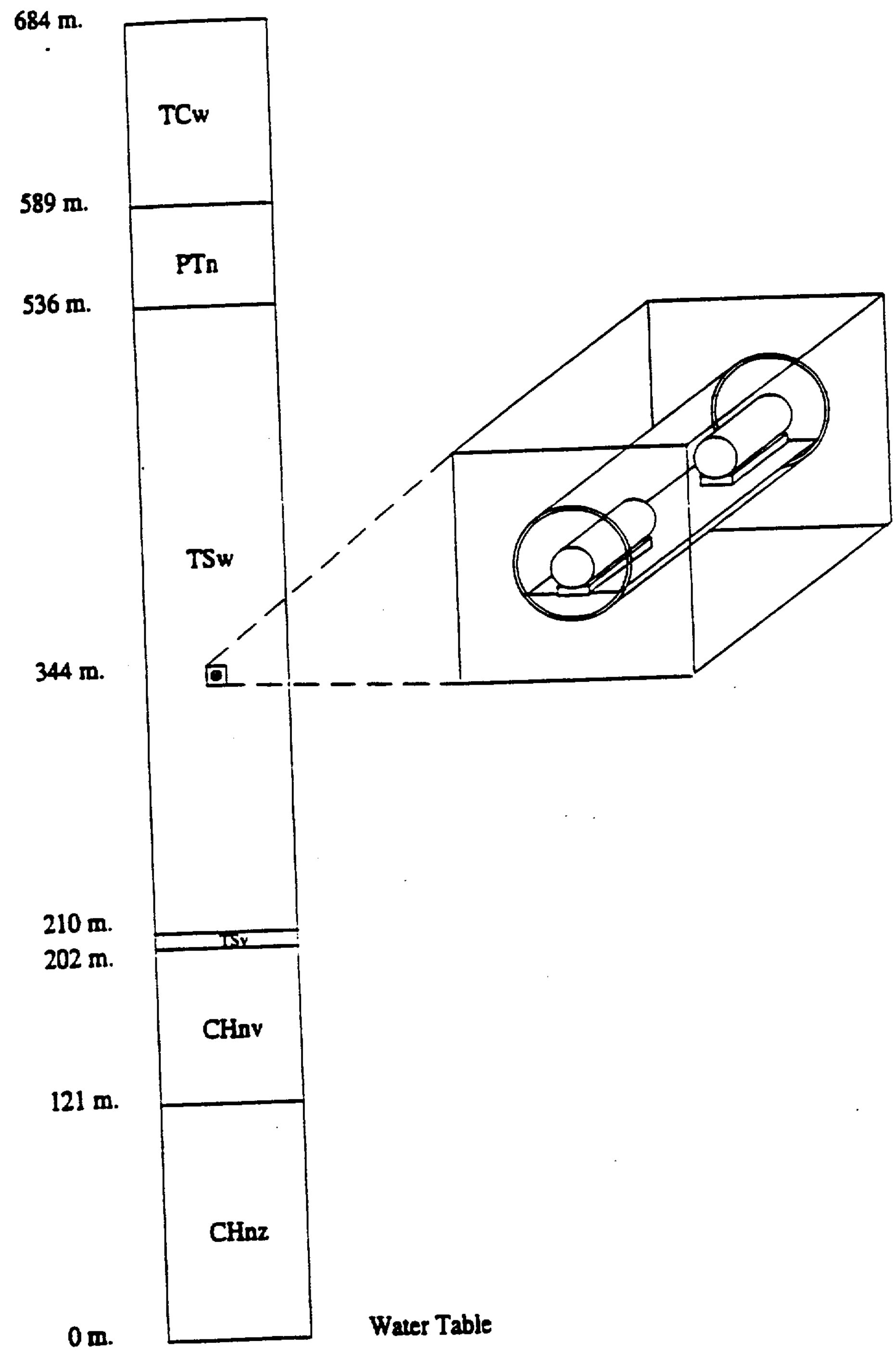
May 22, 1996
Las Vegas, NV

OUTLINE

- Review TSPA 95 Approach and Conclusions
  - Contrast with SNLs TSPA-93

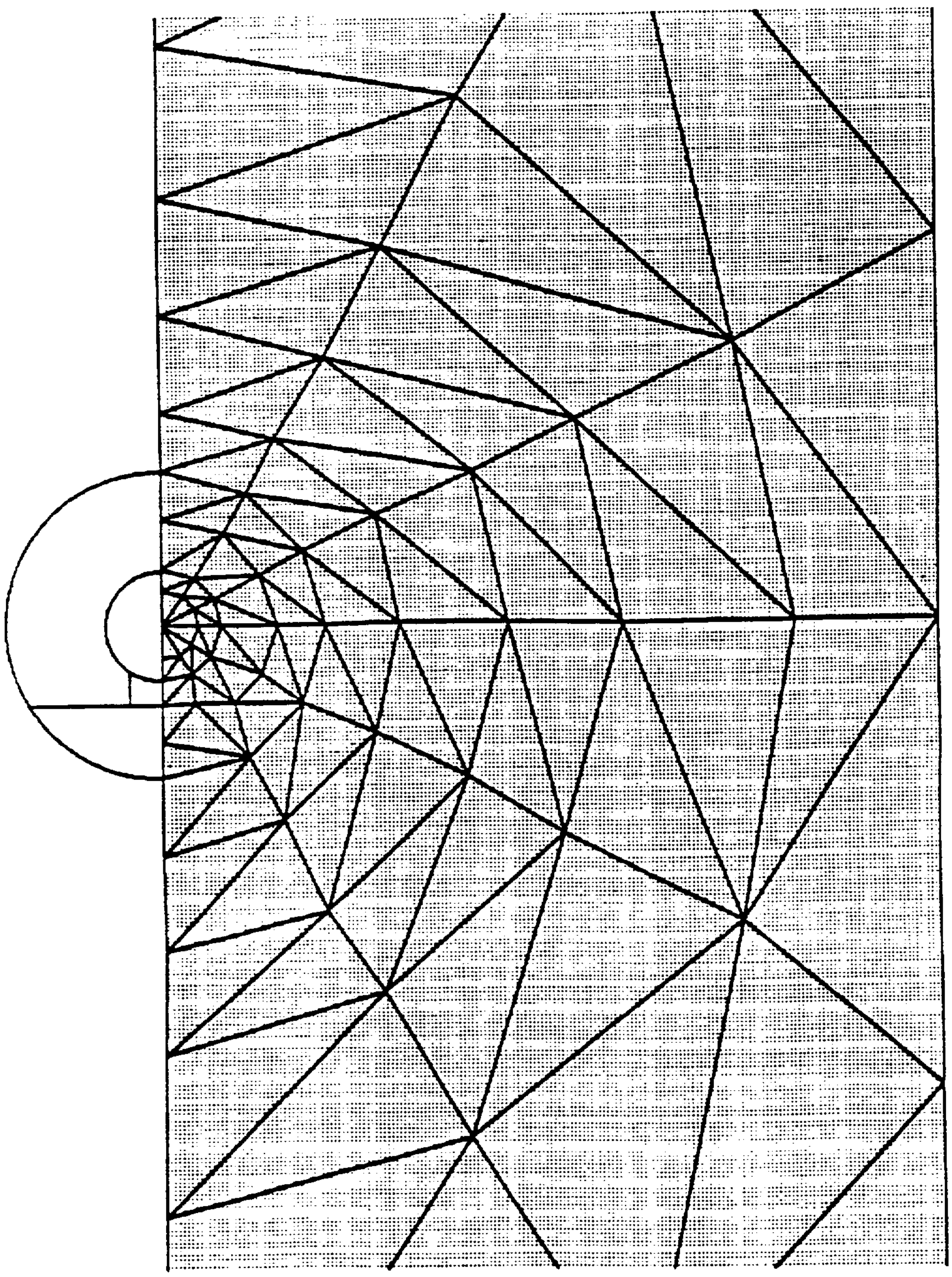
- Present NRC/CNWRA Calculations
  - Can We Reproduce TSPA-95 Results?
  - What If We Use 3D Model?

DESCRIPTION OF TSPA-95 APPROACH



Near-Field Thermal-Hydrologic Conceptual Model

DESCRIPTION OF TSPA-95 APPROACH

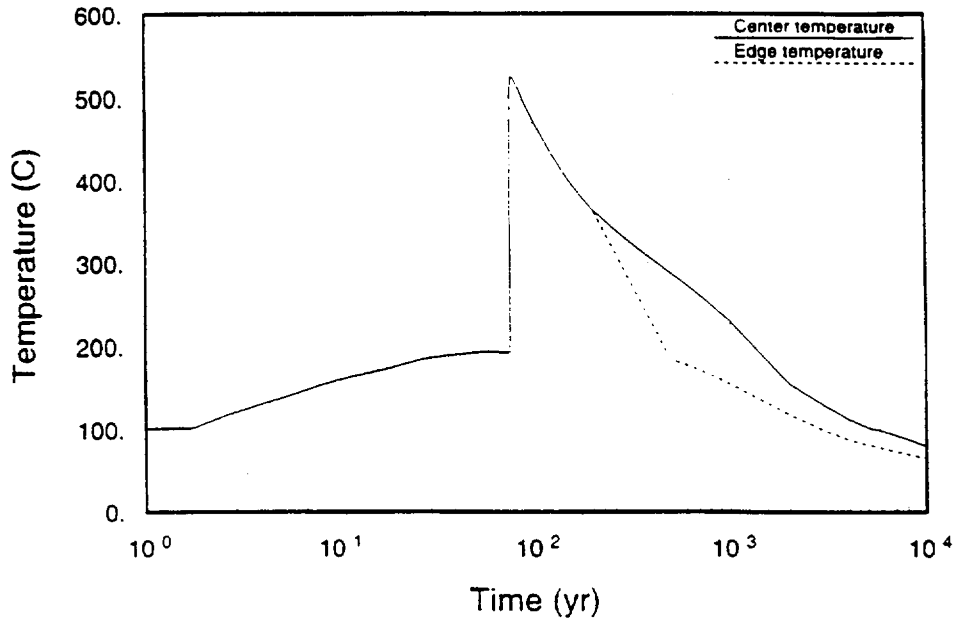


Finite-Element Mesh Used for Drift Scale Thermal-Hydrologic Simulations

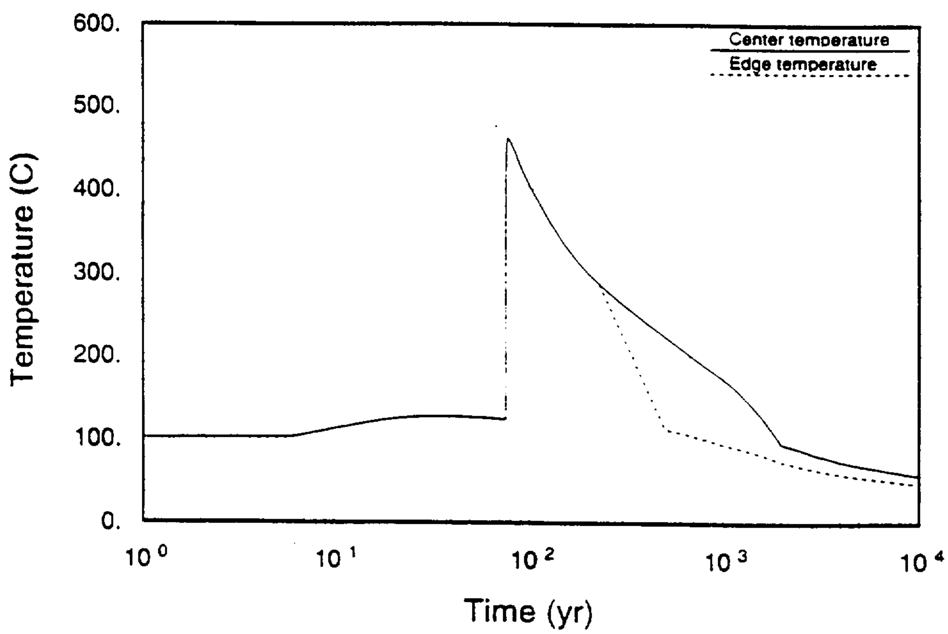
TABLE COMPARING TSPA-93 AND TSPA-95

INPUT	TSPA-93 (Wilson et al., 1994)	TSPA-95 (TRW, 1995)
Code Used	COYOTE (Gartling, 1982) Conduction with adjusted specific heats to simulate boiling	FEHM (Zyvoloski et al., 1995) Multiphase, non-isothermal flow using finite element method
Geometry	3D waste-package scale 7.62 m diameter drift	2D waste-package scale 5.0 m diameter drift
Thermal Loading	114 kW/acre (~125 MTU/acre) 11.88 m waste package spacing 25.4 m drift spacing	for 83MTU/acre (~80 kW acre): 19 m waste package spacing 22 m drift spacing for 25MTU/acre (~24 kW acre): 32 m waste package spacing 45 m drift spacing
Spent Fuel	26 years from reactor 37.3 GWd/MTU average burnup (est. 9.3 MTU/cask)	23 years from reactor 38.5 GWd/MTU average burnup (est. 8.8 MTU/pkg)
Host Rock Properties	Same	Same
Time of Backfill	75 yr	100 yr
Effective Conductivity of Backfill	0.2 W/(m-C)	0.6 W/(m-C)
Maximum Waste Package Temperature	520 °C at 75 yr	170 °C at ~15 yr for 83 MTU/acre 160 °C at ~10 yr for 25 MTU/acre
Waste Package Temperature Increase Promptly After Backfill Emplaced	330 °C	~15 °C both 25 and 83 MTU/acre
Relative Humidity Promptly After Backfill Emplaced	Not Calculated	30% for 83 MTU/acre 50% for 25 MTU/acre

RESULTS FROM SNLs TSPA-93



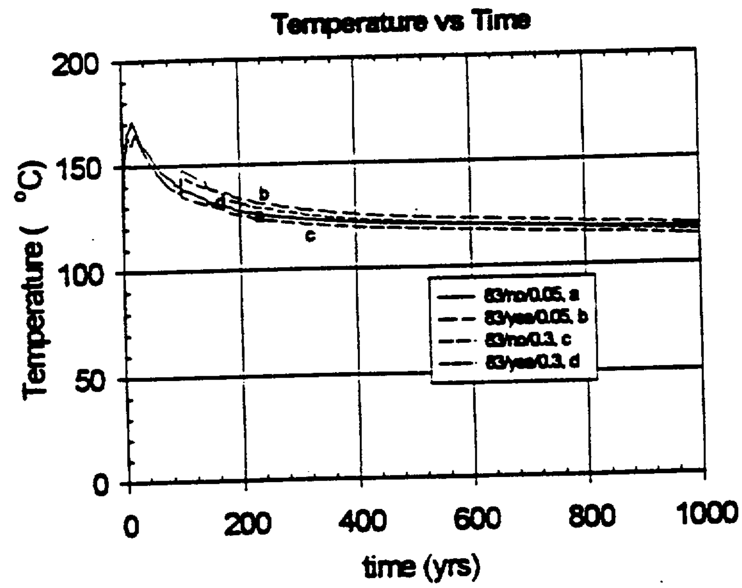
Composite container surface temperature for the 114-kW/acre, in-drift case.



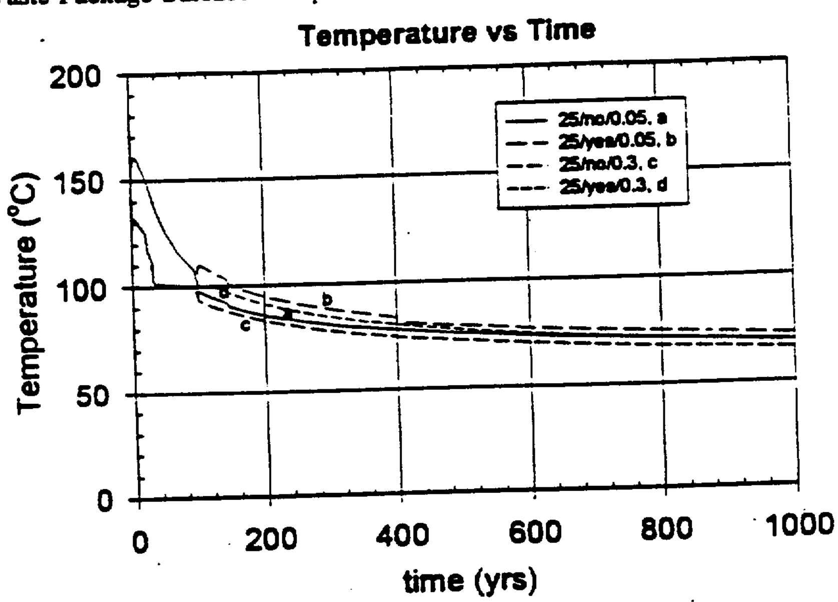
Composite container surface temperature for the 57-kW/acre, in-drift case.

- **3D Drift-Scale Model**
- **Large ΔT Promptly After Backfilling**
- **High Temperatures (T > 100 °C) for Extended Periods**

RESULTS FROM TSPA-95



Waste Package Surface Temperature Predictions for 83 MTU/acre



Waste Package Surface Temperature Predictions for 25 MTU/acre Case

- 2D Drift-Scale Model
- Minimal ΔT After Backfilling
- Lower Temperatures Overall

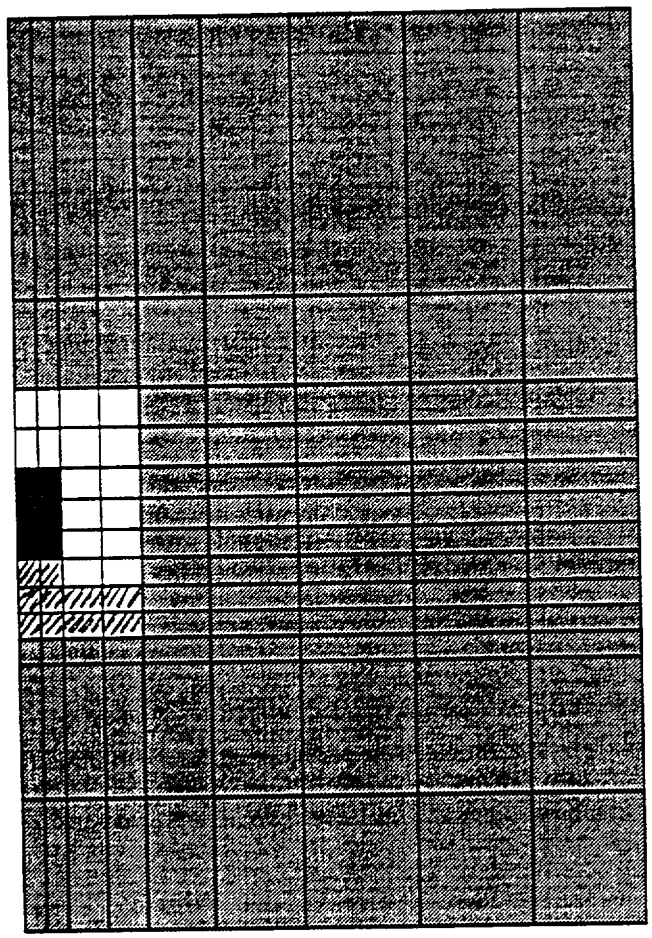
SUMMARY OF TSPA-93 AND TSPA-95 COMPARISON

- TSPA-95 Does Not Explain Differences Between TSPA-93 and TSPA-95
- Modeling Approach Is Different From Previous SNL Analysis
  - TSPA-93 Uses 3D Drift-Scale Model, Conduction Only
  - TSPA-95 Uses 2D Drift-Scale Model, Coupled Heat and Mass Transfer
- Predicted Waste Package Temperatures Differ From Previous SNL Analysis
  - TSPA-95 Predicts Much Smaller ΔT After Backfilling
  - TSPA-95 Predicts Lower Temperatures Overall

DESCRIPTION OF NRC/CNWRA APPROACH

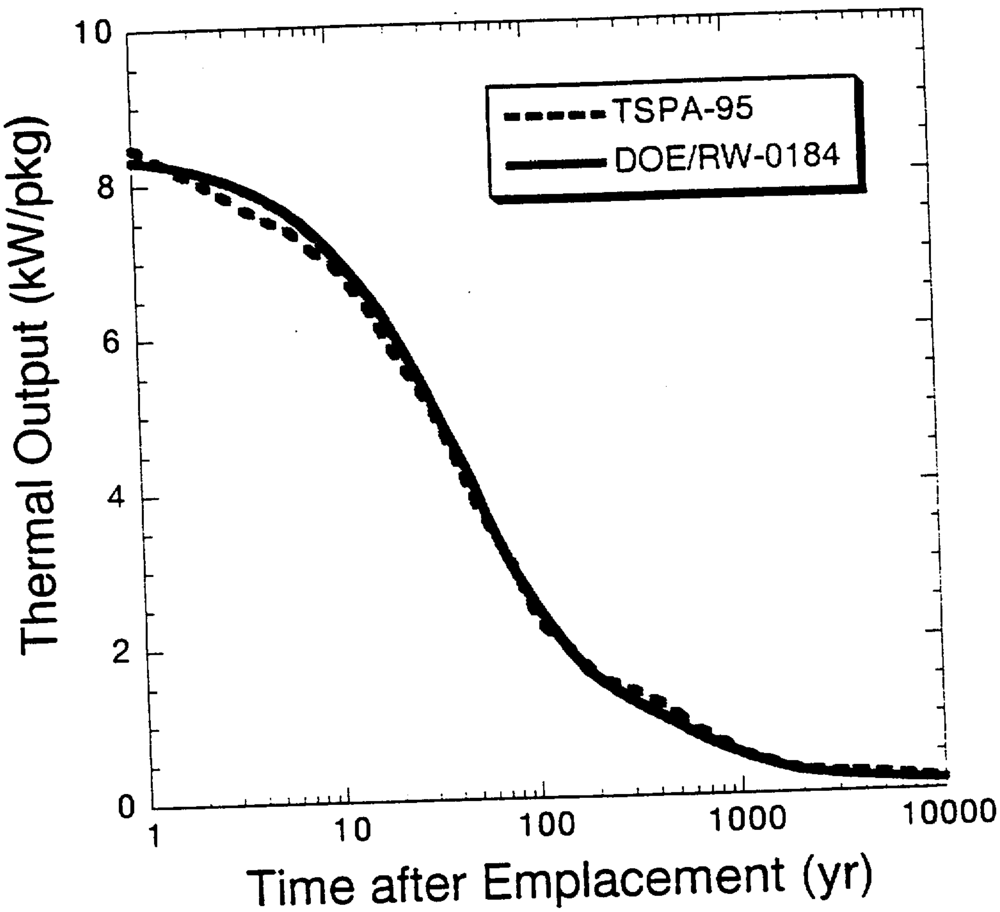
- Use Same Data/Dimensions as TSPA-95
- Evaluate Both 25 and 83 MTU/Acre Cases
- Perform 3 Sets of Calculations:
  - 2D Drift-Scale Using ABAQUS
    Heat Conduction Only
  - 2D Drift-Scale Using MULTIFLO
    Coupled Heat and Mass Transport (Preliminary Version of Code)
  - 3D Drift-Scale using ABAQUS
    Heat Conduction Only

2D DRIFT-SCALE MODEL



- Model Includes:
  - 7 Hydrostratigraphic Layers
  - Excavated Drift
  - Floor
  - Pedestal
  - Waste Package

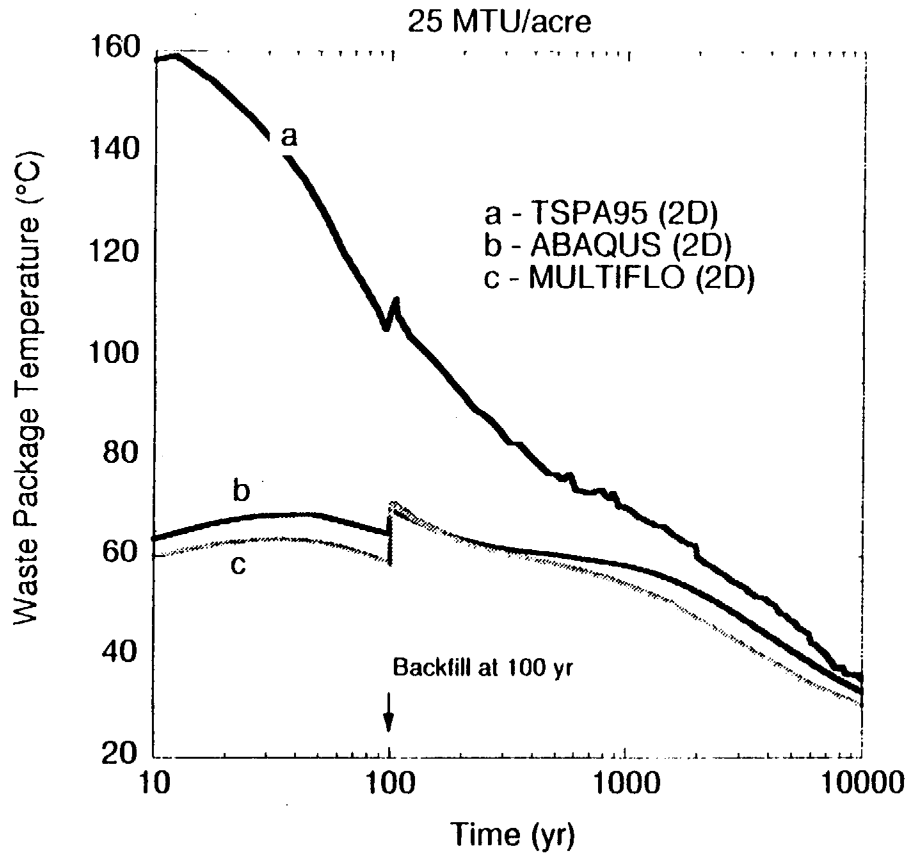
WASTE PACKAGE THERMAL OUTPUT

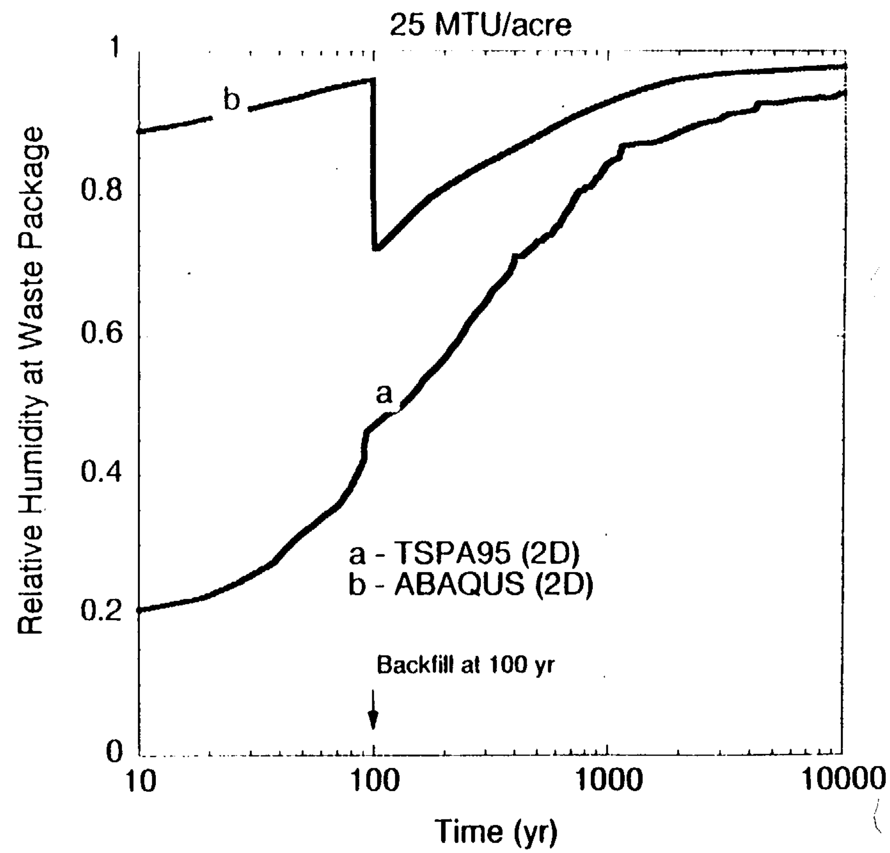


- 23 yr old
- 65% PWR, 35% BWR
- 21 PWR/40 BWR Package
- 0.45 MTU/(PWR Assembly), 0.19 MTU/(BWR Assembly)
- Average Burnup 42 GWd/MTU for PWR, 33 GWd/MTU for BWR
- Average Cask 8.8 MTU, 38.5 GWd/MTU

Data from DOE/RW-0184, Vol. 2, Appendix 1C

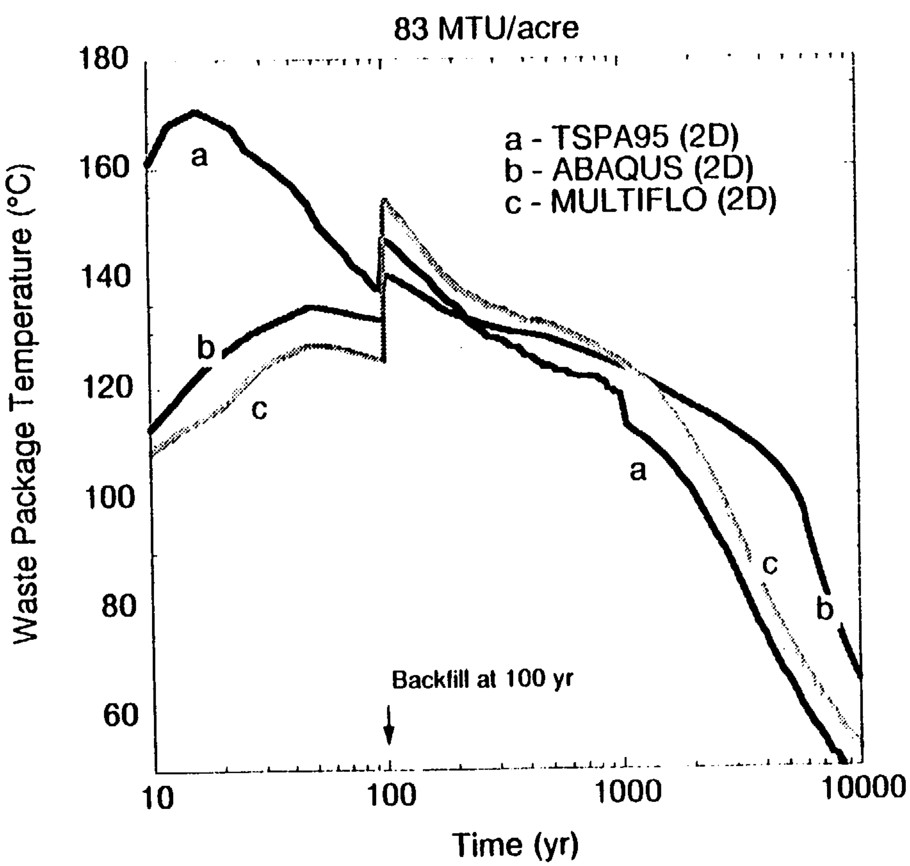
2D DRIFT-SCALE RESULTS FOR 25 MTU/ACRE

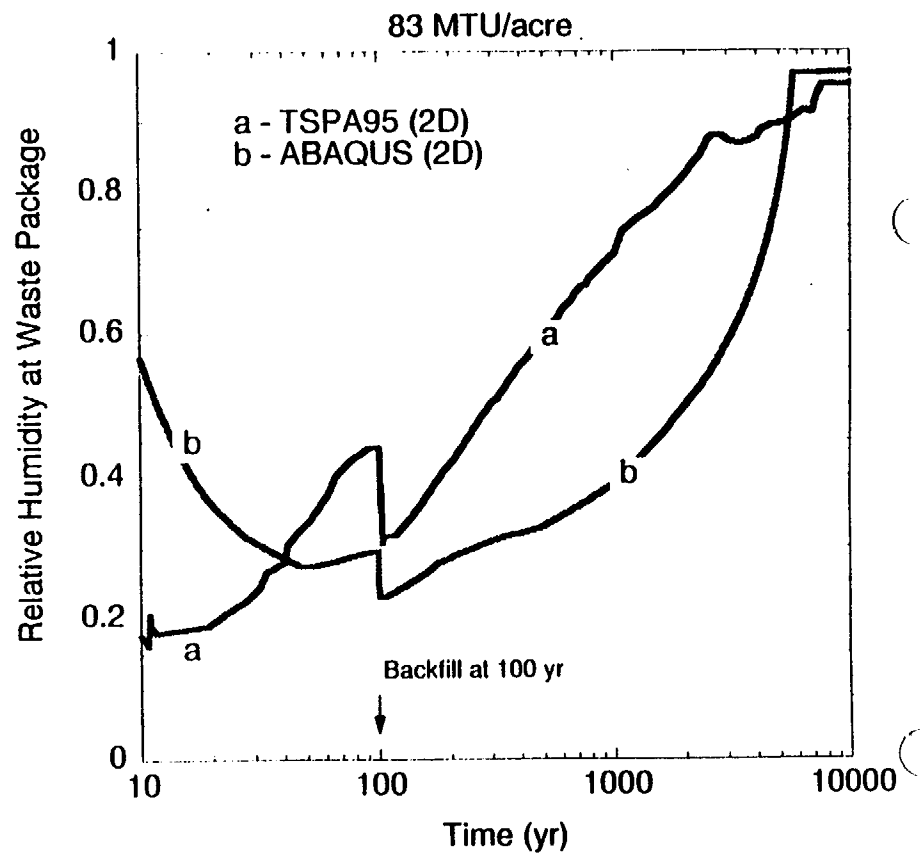




- **TSPA-95 Thermal Output Boosted by 32/30 = 1.07 for 25 MTU/acre and 19/15 = 1.27 for 83 MTU/acre**

2D DRIFT-SCALE RESULTS FOR 83 MTU/ACRE

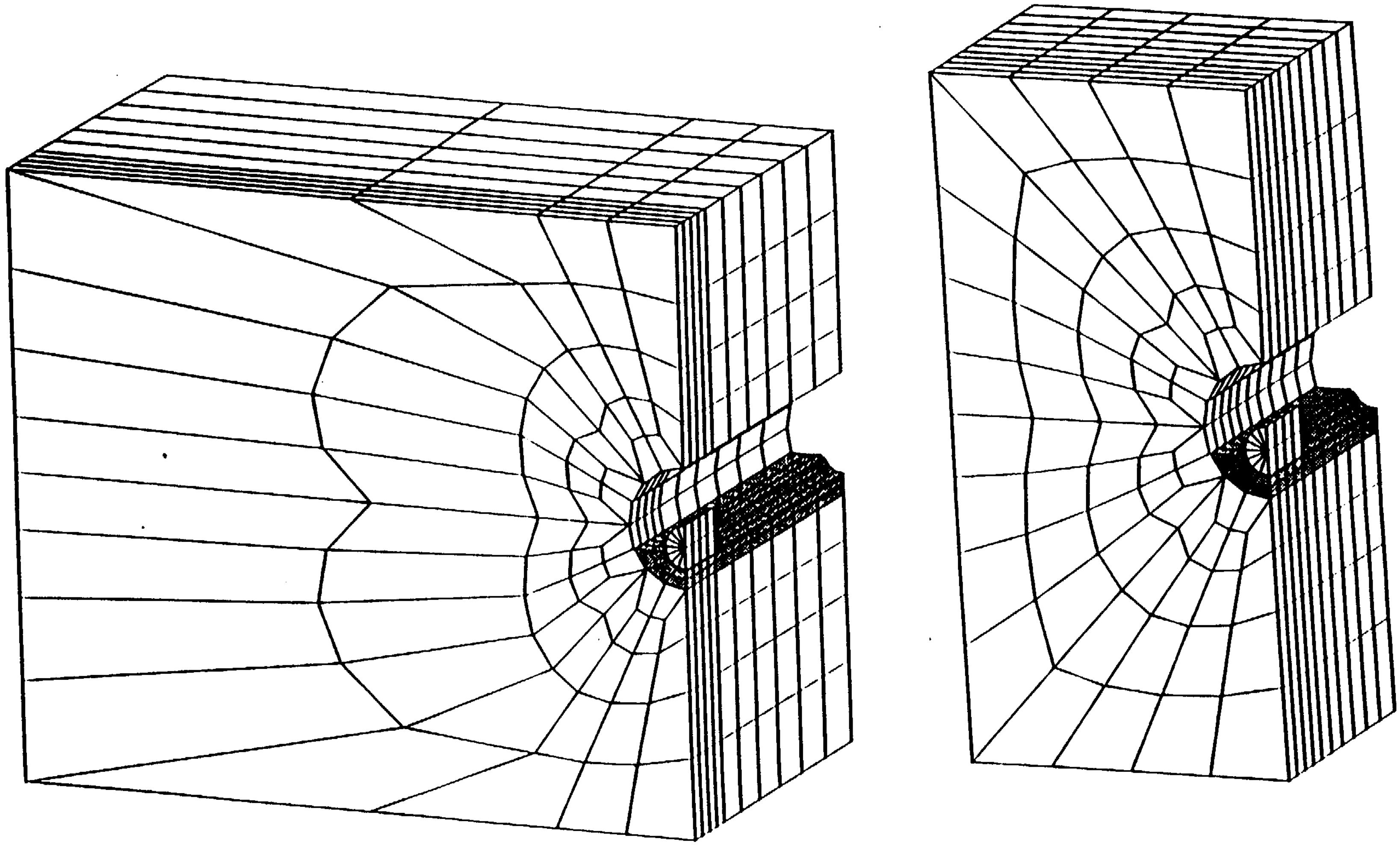




SUMMARY OF 2D DRIFT-SCALE CALCULATIONS

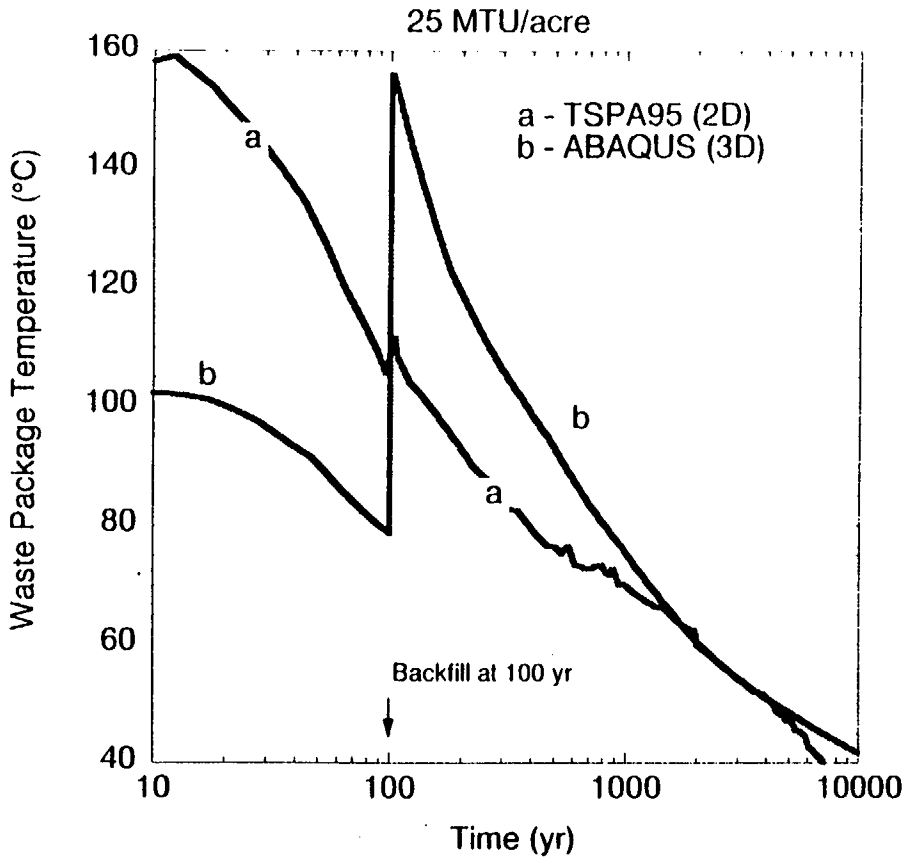
- For 25 MTU/acre, TSPA-95 Results Have:
  - Higher Peak Temperature Prior to 100 yr
  - Higher Temperatures for All Times
  - No Decrease in Relative Humidity at 100 yr
  - Lowest Relative Humidity
- For 83 MTU/acre, TSPA-95 Results Have:
  - Higher Peak Temperature Prior to 100 yr
  - Slightly Lower Temperatures At Long Times
  - Highest Relative Humidity

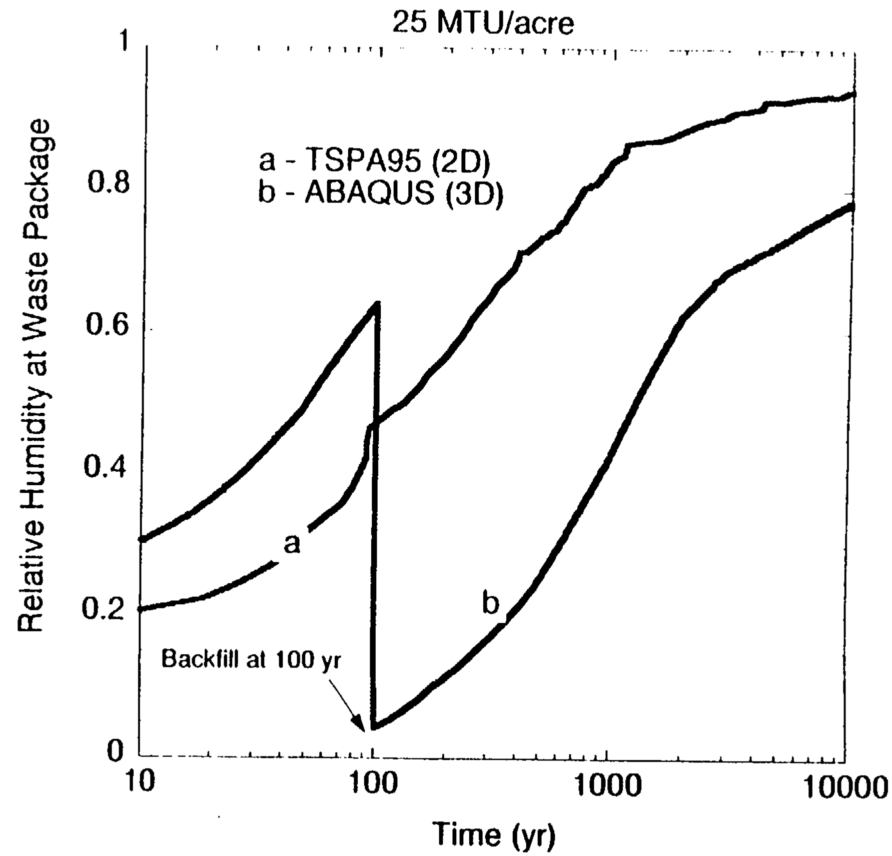
3D ABAQUS DRIFT-SCALE MODEL



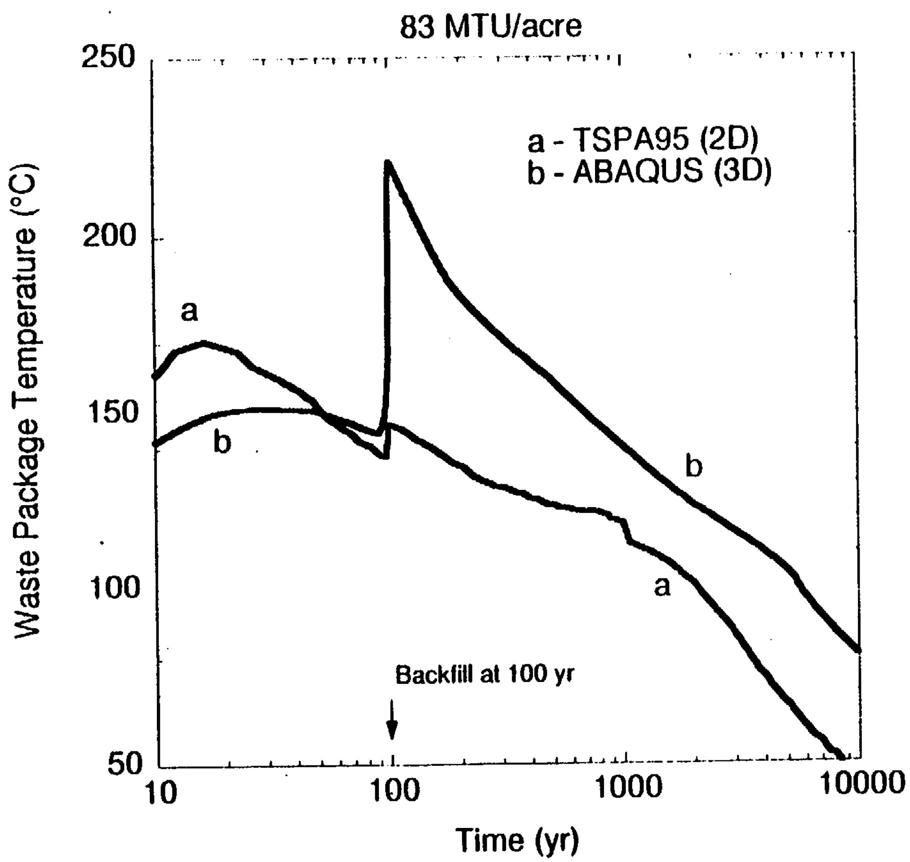
- **Motivation: 2D Model Underpredicts WP Temperature Due to Spatial Averaging of Source Term Along Drift**

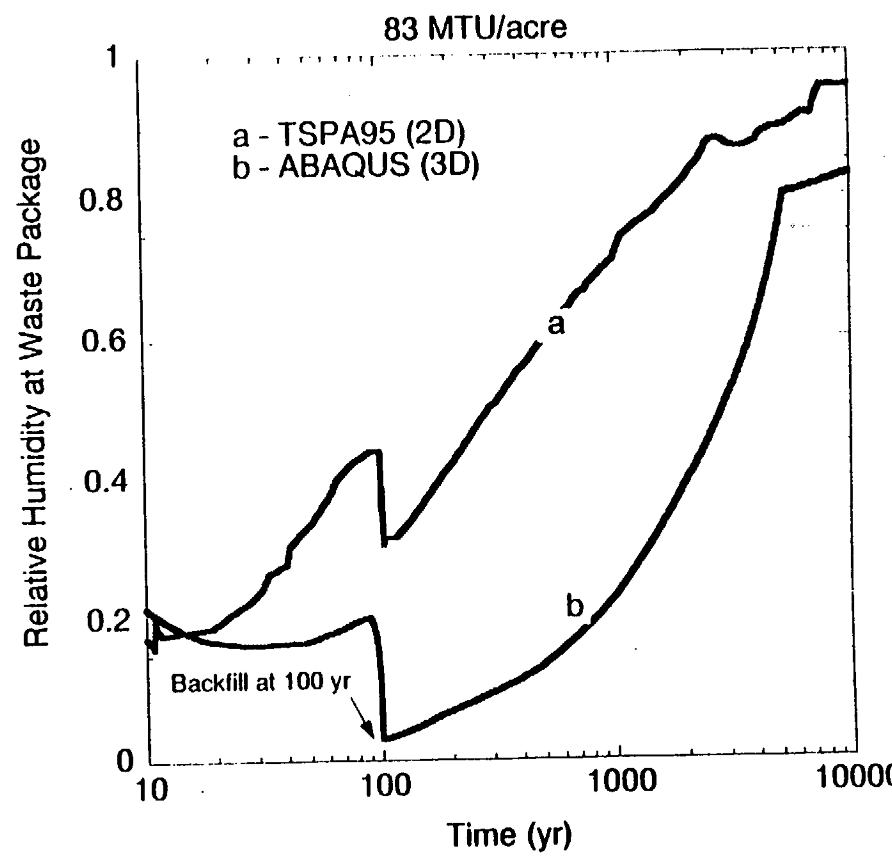
3D MODEL RESULTS FOR 25 MTU/ACRE





3D MODEL RESULTS FOR 83 MTU/ACRE





SUMMARY OF 3D MODEL RESULTS

- For 25 MTU/acre and 83 MTU/acre Cases, TSPA-95 Results Have:
  - Underpredicted Waste Package Temperature (may not be conservative)
  - Overpredicted Waste Package Relative Humidity (may be more conservative)

SUMMARY

- Unable to Reproduce Some Results in TSPA-95
  - TSPA-95 Has Higher Peak Temperatures Before Backfill
    Due To Adjustments of Heat Source?
    Due to Effective Conductivity of Drift?
- TSPA-95 Results Different Than TSPA-93
  - No Significant ΔT After Backfill
  - Lower Temperatures Throughout
- 2D Models As Applied May Underpredict Waste Package Temperature, and Overpredict Humidity

POINTS FOR DISCUSSION

- Review Effective Conductivity of Drift Prior to Backfilling
- Use of 2D Versus 3D Model
  - Improve Predictions of Waste Package Temperature and Humidity
  - Avoid Averaging Heat Source Over Package Spacing Along Drift
- In Future TSPAs, Discuss How New Analyses Relate to Previous Analyses
  - Rationale for Changes in Approach
  - Rationale for Changes in Dimensions, Properties, Etc.
  - Highlight Significant New Results and Conclusions

Total System Performance Assessment Container Life and Source Term Issues

Participants

T. Ahn, G. Cragnolino, P. Lichtner, H. Manaktala, W. Murphy, N. Sridhar, and J. Walton

Center for Nuclear Waste Regulatory Analyses

Presented by

Narasi Sridhar

Approach Used in TSPA-95 for Container Life and Source Term

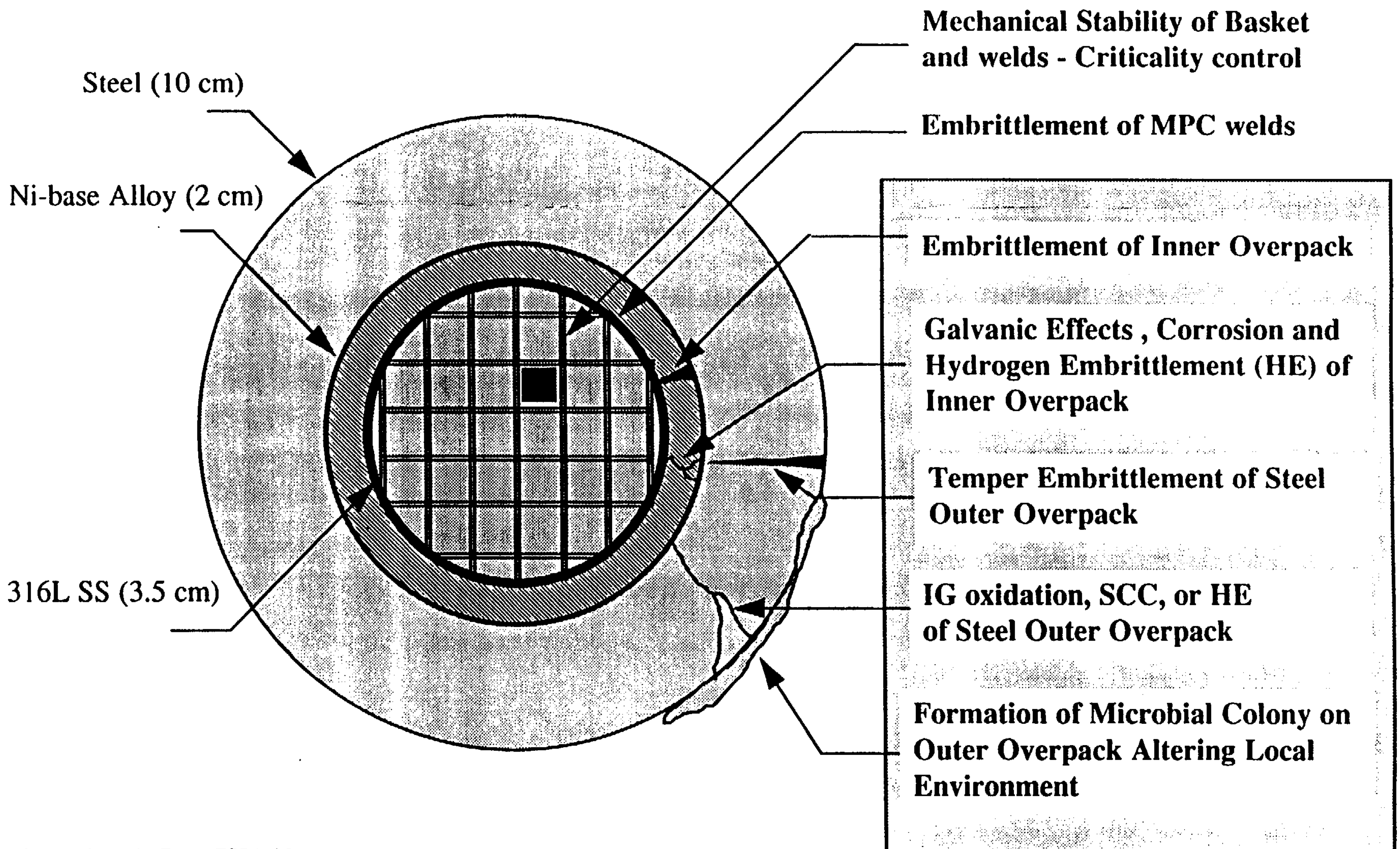
❑ Container Life

- Humid air corrosion below a critical relative humidity (RH) based on extrapolation from atmospheric corrosion data, allowing for time of wetness
- Pitting included as a pitting factor for outer overpack
- Aqueous corrosion based on extrapolation of data from polluted river water and tropical lake water
- Pitting considered as a parabolic rate law for inner overpack

❑ Source Term

- Release of fission products and actinides dependent on matrix dissolution rate and solubility
- Matrix dissolution proportional to exposed surface area of fuel (dry oxidation has no effect on surface area)
- Actinide release assumed to be increased by a factor of 3 by colloids
- Empirical calculation of the effect of near-field chemistry on spent fuel dissolution

Failure Processes in The ACD Waste Package Design



Factors To Be Considered in Waste Package Performance Assessment

- ❑ Thermal embrittlement during initial hot, dry period
- ❑ Dry oxidation
- ❑ Corrosion in alternate wet-dry environment - more severe than either dry or wet environment
- ❑ Bounding environment chemistries
- ❑ Initiation and rates of corrosion penetration
- ❑ Rates of spent fuel dissolution and radionuclide mobilization

Thermal Embrittlement of Steel Overpack

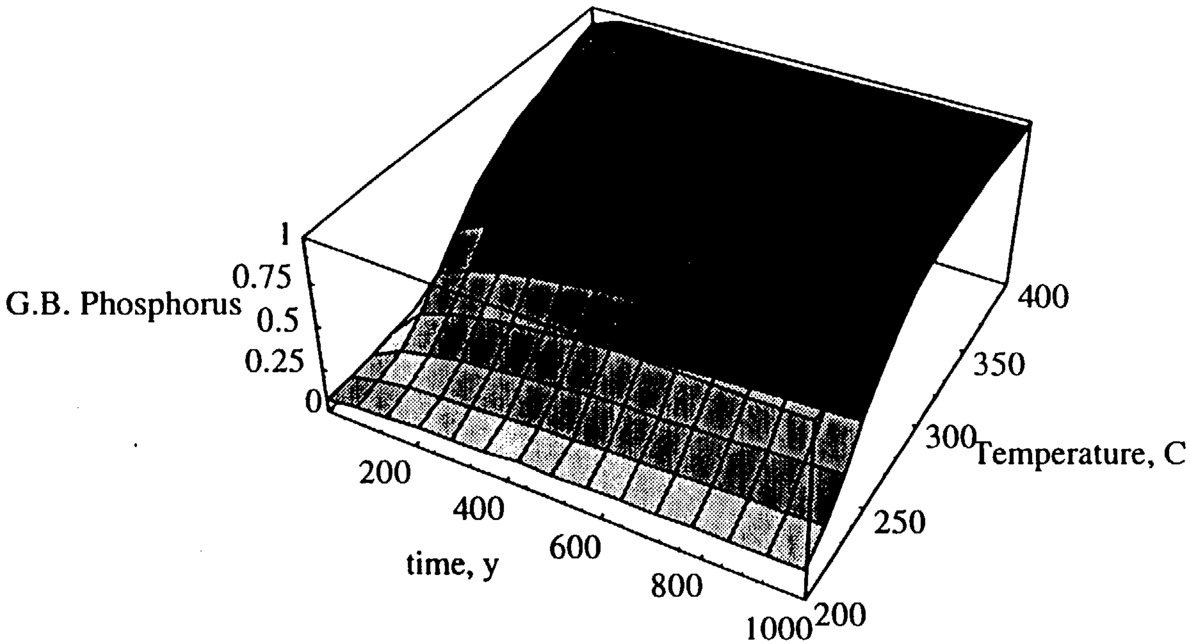
❑ Bases for Concern

- Embrittlement can occur due to P segregation to grain boundaries and residual stress as well as seismic effects
- Considerations of design for corrosion should be balanced against considerations for embrittlement

❑ Points For Consideration

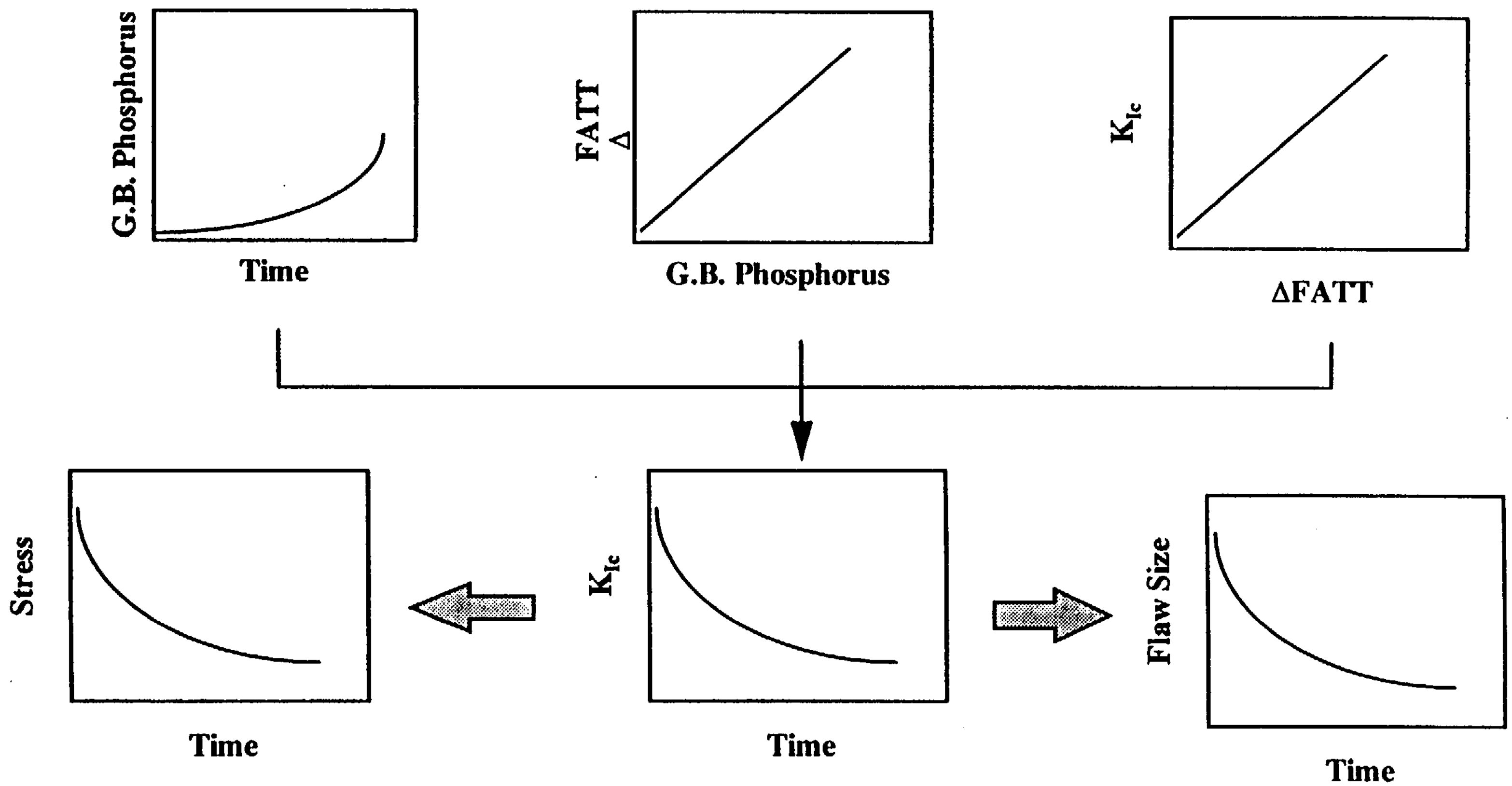
- Determination of overpack wall temperatures for various AMLs, fuel histories
- Determination of change in fracture toughness due to thermal aging
- Determination of residual stresses and acceptable flaw size

Thermal Embrittlement of Steel Overpack



- Modeling thermal embrittlement can be done by calculating segregation of P and comparing it to a critical concentration
- Embrittlement is greater for low-alloy steel than C-Mn steel
- Embrittlement is increased by large grain size (e.g. due to welding)

An Approach to Calculating Potential For Thermal Embrittlement



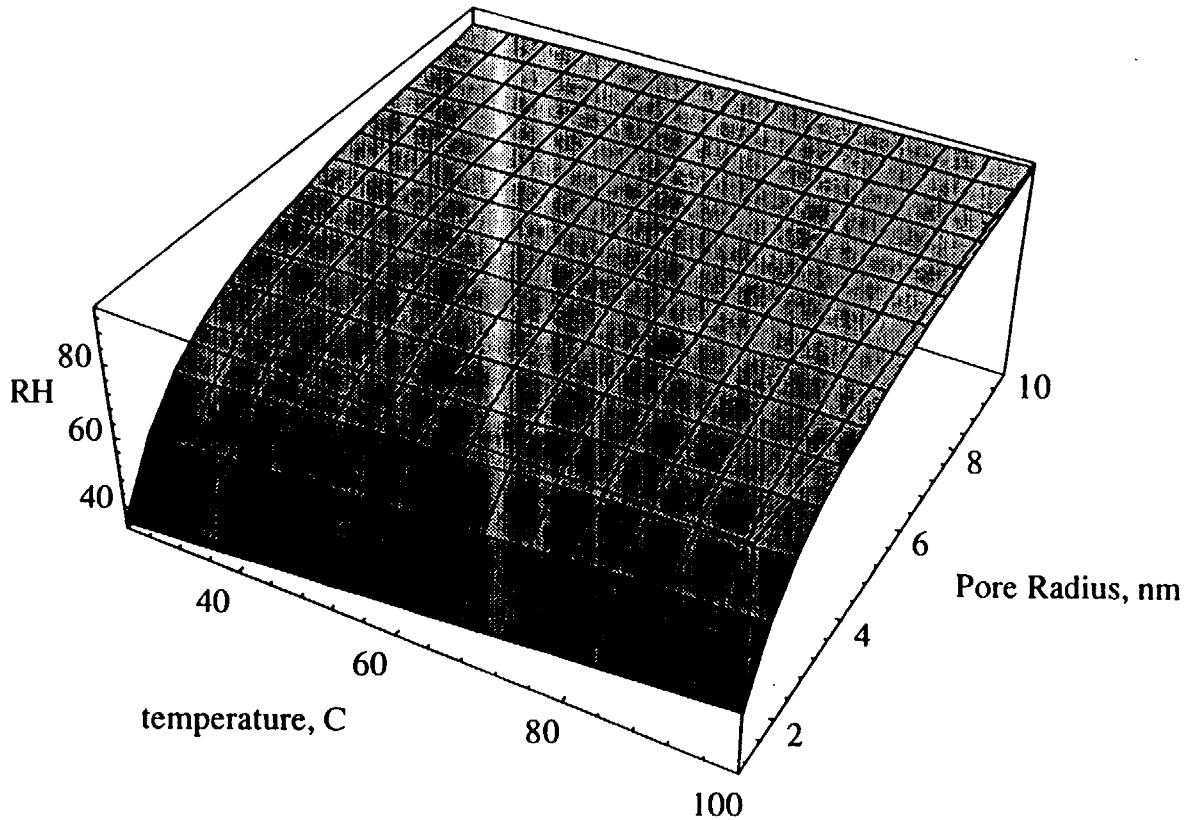
Dry Oxidation

- **Concerns**
  - The rate of uniform oxidation is considered to be insignificant
  - The potential for intergranular oxidation and its rate is unknown at present: depends upon temperature, grain boundary diffusion, segregation of alloying elements
  - Brittle intergranular oxides can be easy crack paths
- **Points for Consideration**
  - Possible input to thermal embrittlement, pitting, or stress corrosion cracking models

Conditions for Rewetting

- **Concern**
  - The critical RH (70%) in TSPA does not include the effects of chemistry or corrosion/oxidation products on overpack surface
    - Salt films can lower critical RH to values as low as 33%
    - Porous oxide scale has been known to affect critical RH
- **Points For Consideration**
  - The effects of near-field chemistry on rewetting time
  - Salt film formation affected by back flow of pure water - results of coupled models
  - Mineral precipitation or dissolution effects on fracture flow

Corrosion Product Capillary Effects



- Dry oxidation causes porous oxide scale
- The critical RH at which water film is stable is lower for smaller pore size
- "Humid air" corrosion can initiate earlier than assumed by 70% cut off

Corrosion in Humid Air

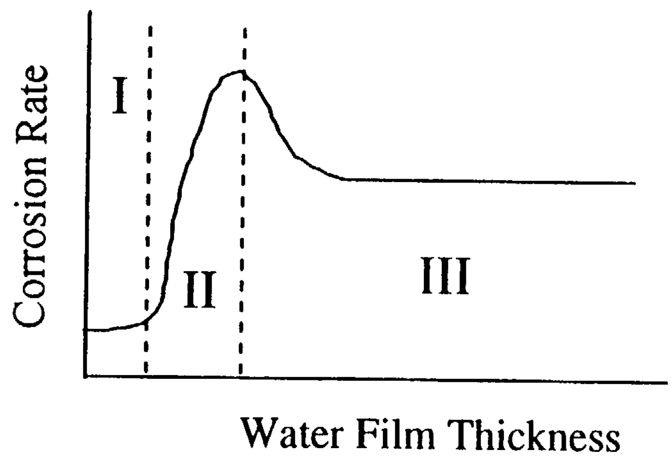
❑ Concerns

- Corrosion in alternate wet and dry conditions not completely determined by the cumulative time above a critical RH
- Use of parametric equation developed from atmospheric corrosion tests to much higher temperatures and longer time periods may be non-conservative
- The data used in TSPA-95 are predominantly developed for weathering steels. The atmospheric corrosion rates are highly dependent on the grade of steel
- There is no mechanistic basis for the approach adopted

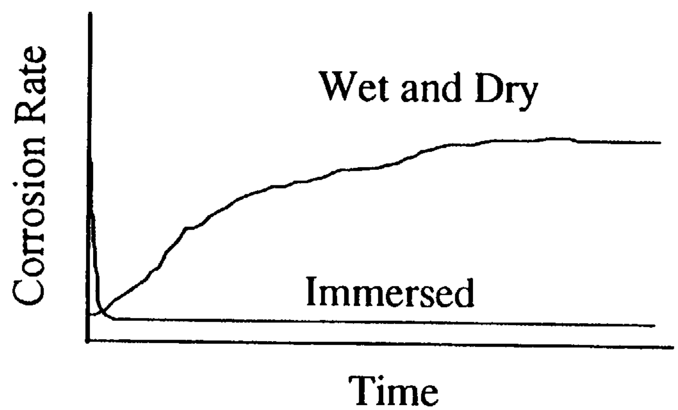
❑ Points For Consideration

- Process models for humid air corrosion
- The data for appropriate materials

Corrosion in Wet-Dry Cycles

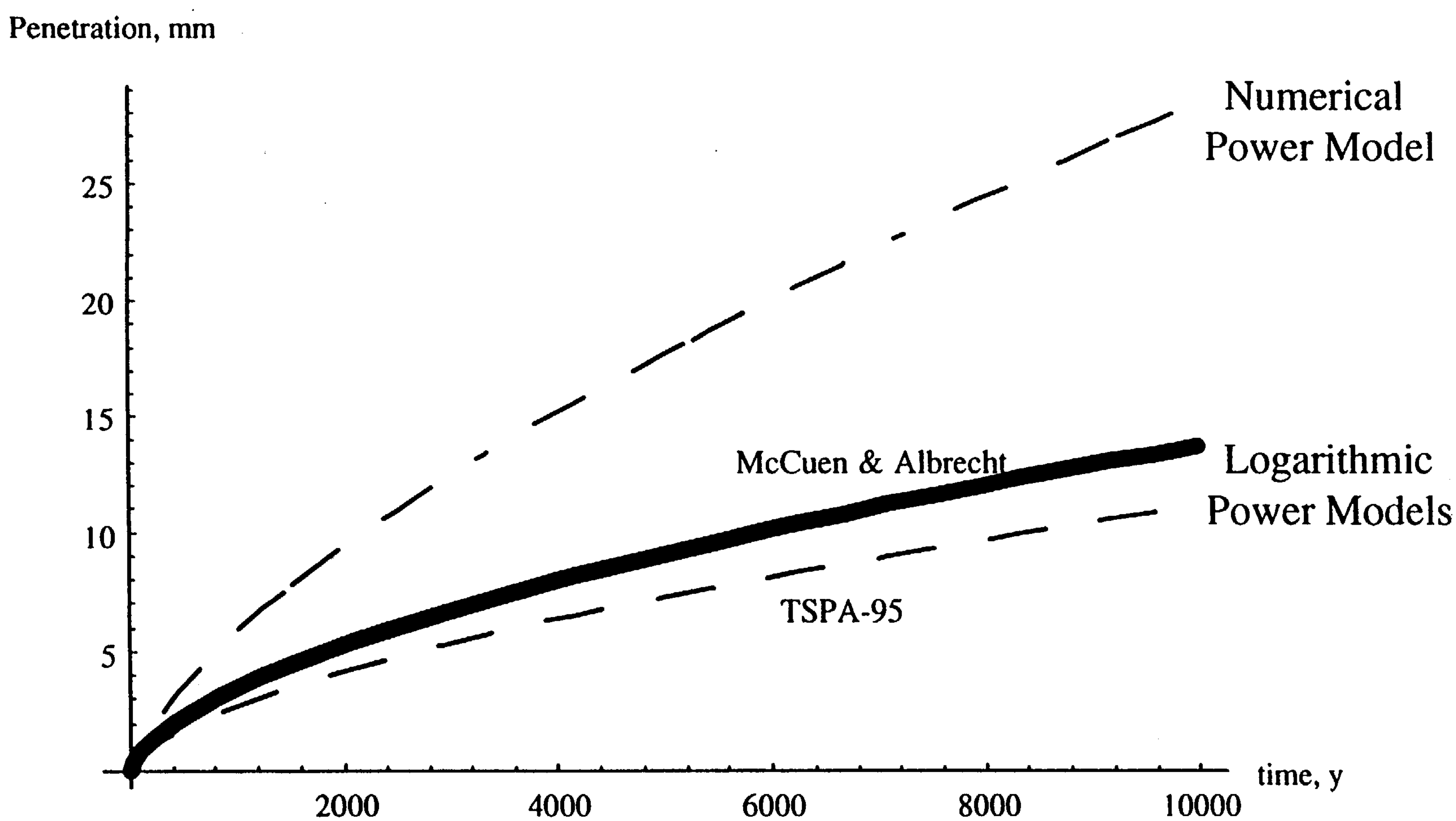


- **Effect of water film thickness on corrosion**
  - Accumulation of dissolution products (Region I)
  - Increased access to oxygen (Region II)



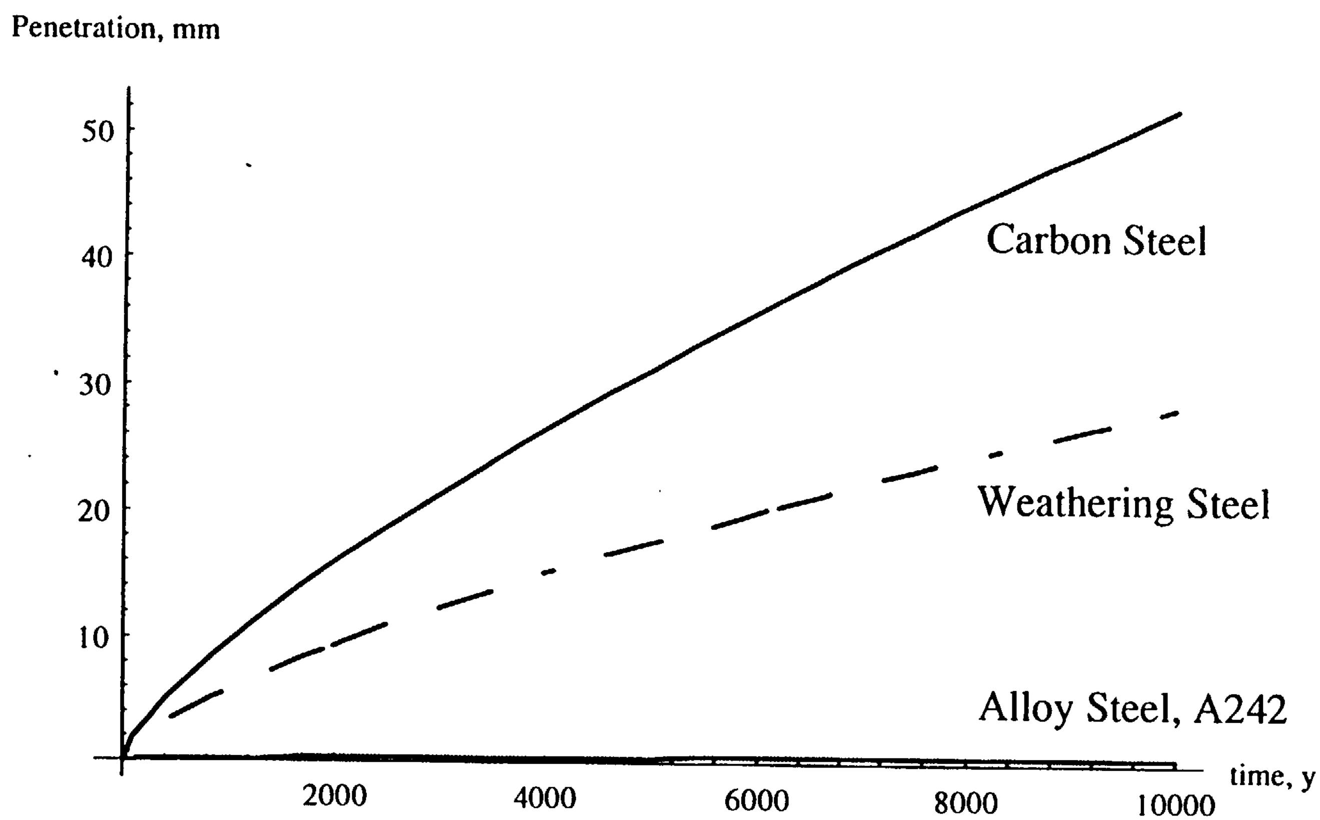
- **Effects of prior oxidation**
  - Additional redox reaction of FeOOH can increase corrosion rate

Effect of Extrapolation Model
(Industrial Site, Rankin, PA)
McCuen and Albrecht (1994)



Effect of Steel Composition on Corrosion Rate (Industrial Site, Rankin, PA)

McCuen and Albrecht (1994)



Pit Penetration Rate Under Aqueous Condition

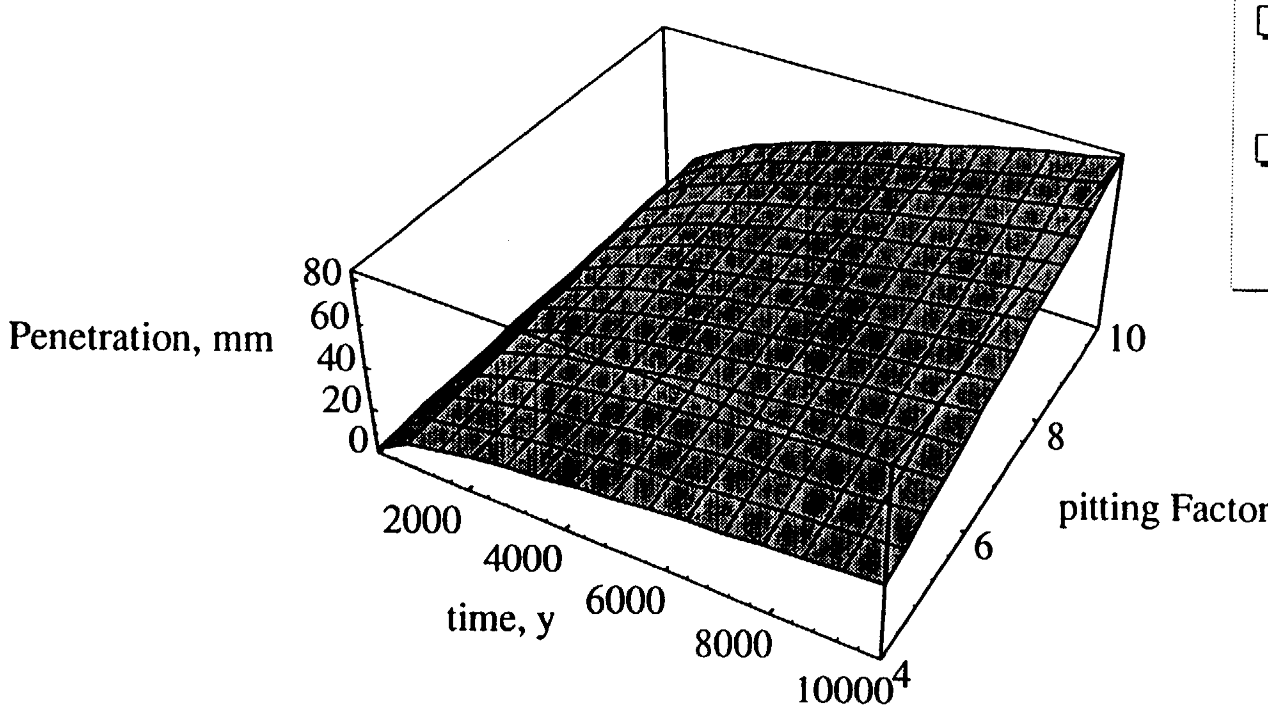
❑ Concerns

- The pitting factor approach used in TSPA may not be conservative
- Pitting factor does not consider conditions for initiation of localized corrosion.
- Most data indicate much higher penetration rates once stable pitting is initiated
- The effect of potential on pit penetration rate for inner overpack is not considered

❑ Points For Consideration

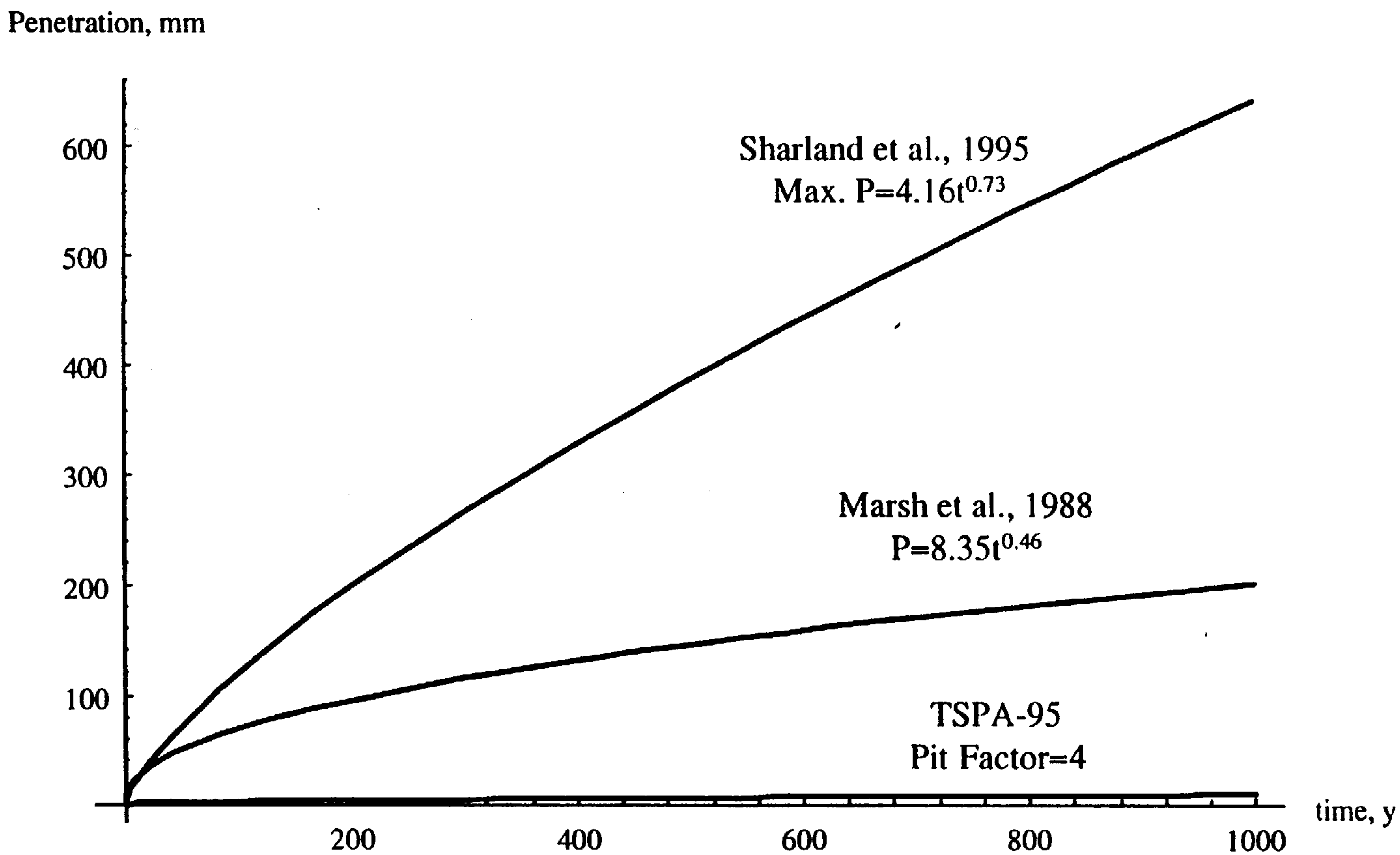
- Literature data on pit growth rates
- Abstraction of stable pit growth models
- Use of repassivation potential versus pitting potential

Effect of Pitting Factor on Penetration



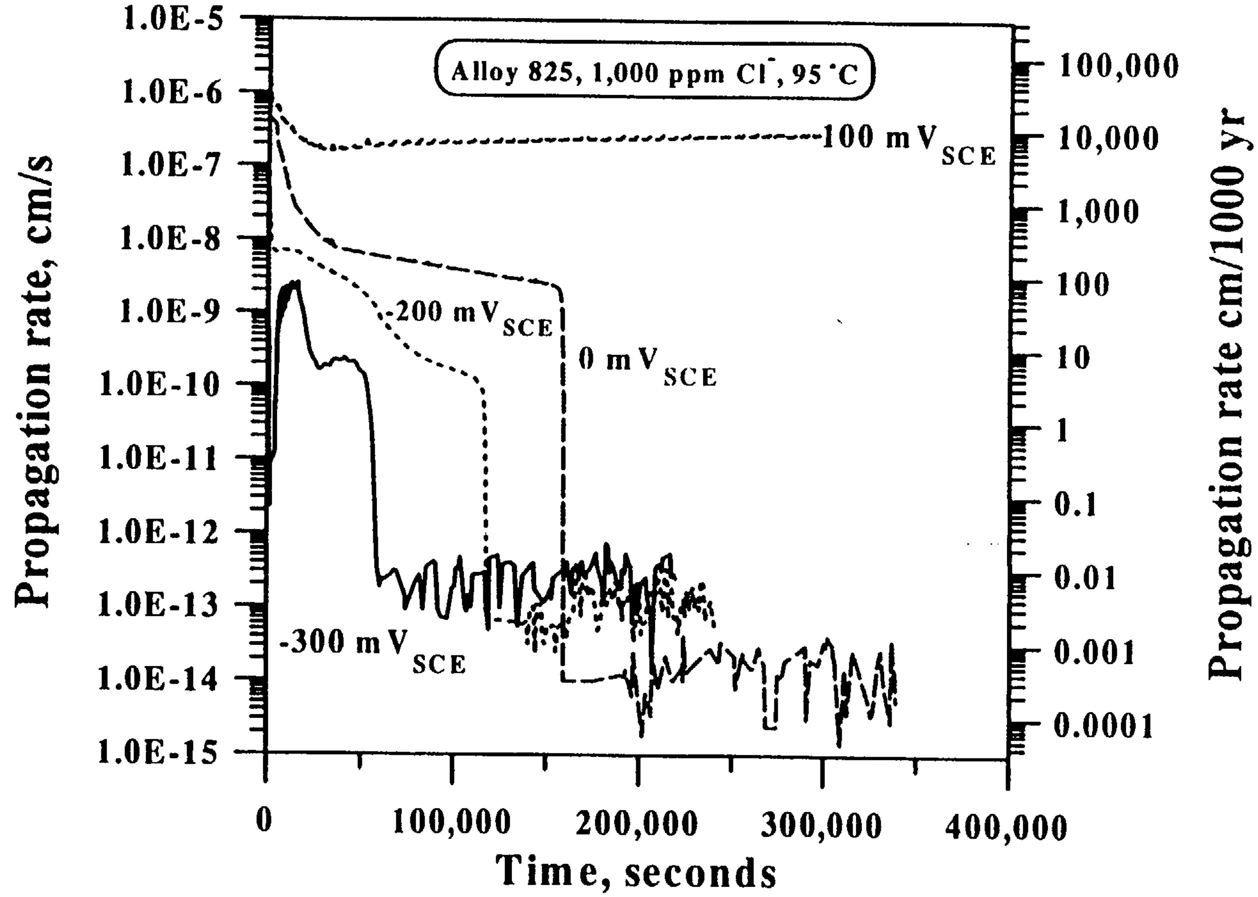
- Rationale for the choice of pitting factor
- Observed pitting factors greater than 4

Pit Propagation in Aqueous Environment



Pit Growth Rates of Alloy 825
(Dependence on Potential)

Galvanic effects with steel may reduce potential and hence growth rate



Effects of Near-Field Environment Evolution

- **Concerns**
  - Sufficient range of chemistry contacting the waste package may not have been considered for container life and source term
  - No process models currently being used for considering the environmental parameters used in the abstractions
- **Points For Consideration**
  - Use of coupled thermo-hydrological-chemical calculations for abstractions
  - The local environment within cracks and pits
  - The abstraction of the effects of microbial interactions

Effects of Bounding Environment Chemistries

- **Alkaline Environments Predicted by Evaporative Effects and Cement Reactions**
  - Increase the likelihood of localized corrosion of steel - depending on Cl^-
  - Increase the likelihood of stress corrosion cracking - depending upon HCO_3^-
  - Decrease corrosion rate due to passivation
  - Increase dissolution of glass waste form
- **Acidic Environments Predicted by Steel Corrosion in Cracks/Pits**
  - Increase the likelihood of inner overpack corrosion
  - Increase solubility of U(VI) and radionuclides
- **Microbial Actions**
  - Can increase corrosion potential considerably (sea water experience)
  - Can produce deleterious reduced sulfur species

Release of Radionuclides

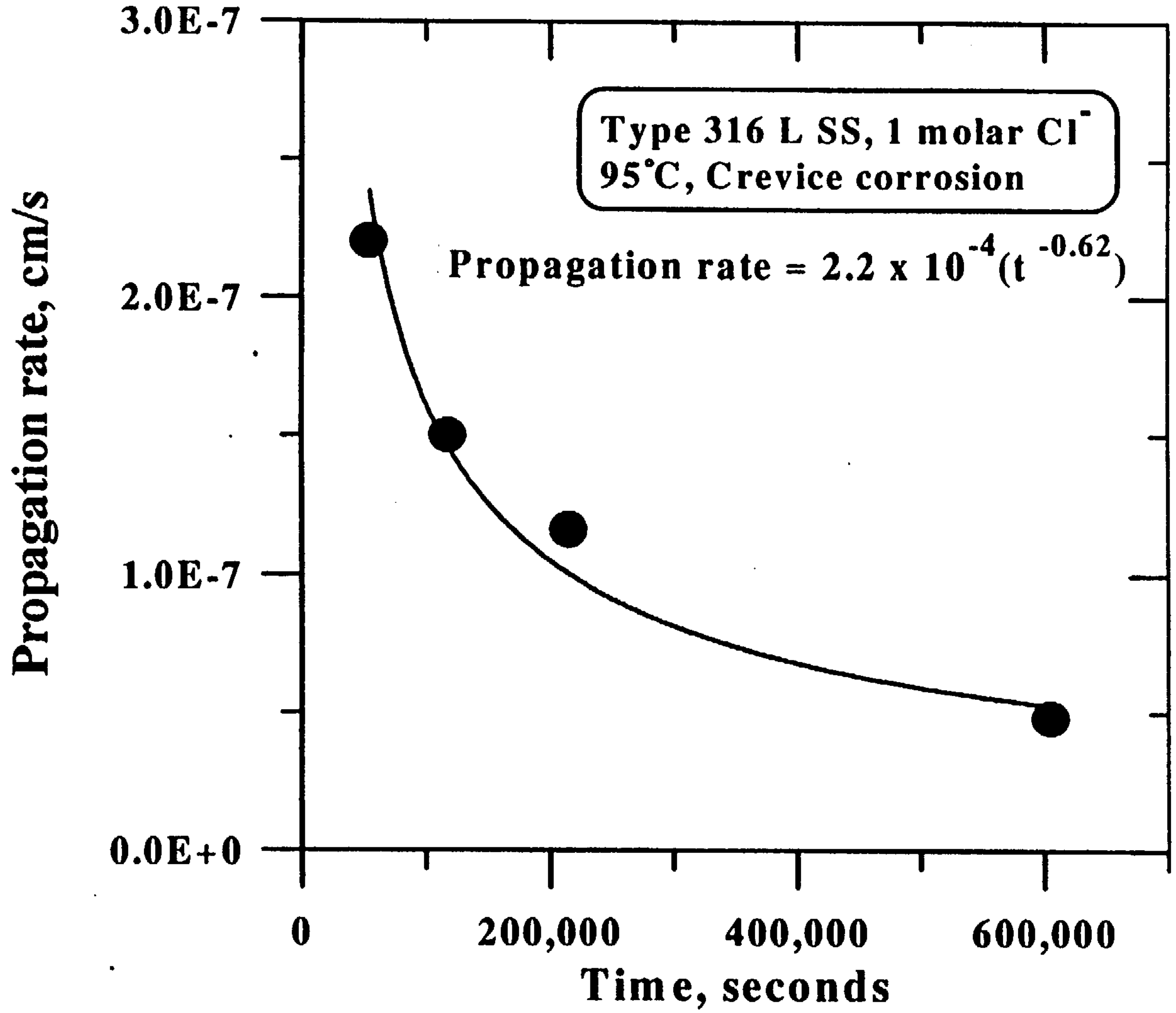
- **Dry oxidation can increase surface area more than assumed in TSPA ($UO_{2.4}$ about 100 times; U_3O_8 about 1000 times)**
  - Release of C-14, Tc-99, I-129, Cl-36 by diffusion through oxidized fuel
  - Assumed particle radius: 1 micron
  - Diffusivity assumed to be the same as for Xe-133
  - Complete release time: $0.6x(radius)^2/D$
    - at 200 C: 4060 years
    - at 100 C: 371,000 years

- **Colloidal release of actinides could be significant**
  - Formation (ANL, 1995) and transport (Kim, 1995)

Summary

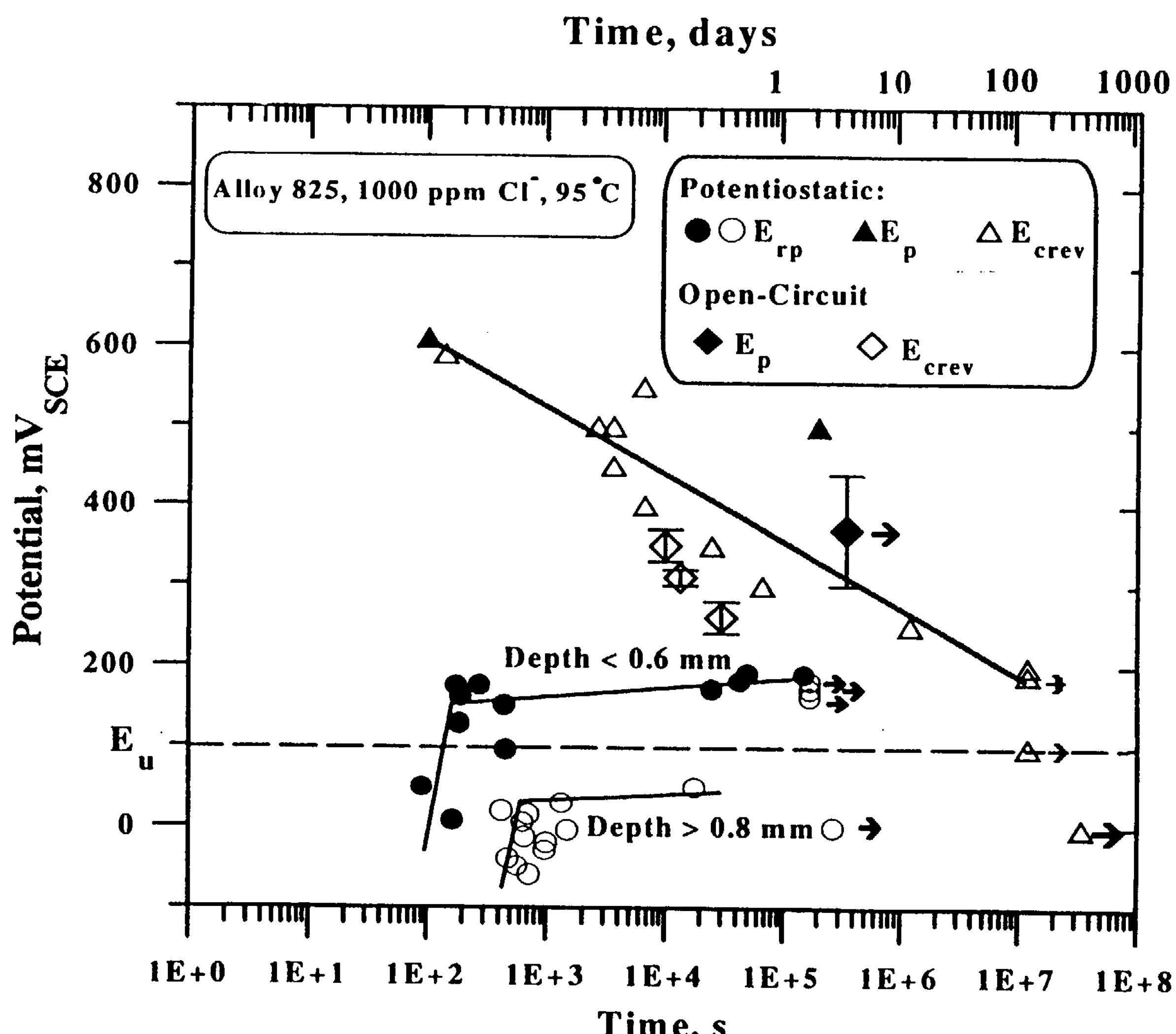
- **Many potential failure modes are not presently considered**
  - Thermal embrittlement
  - Alternate wet and dry corrosion
  - Crevice corrosion
  - Stress corrosion cracking
  - Microbially influenced corrosion
- **The abstractions used in TSPA-95 appear to be non-conservative**
  - May have insufficient mechanistic justification
  - The performance calculations should consider a wide range of near-field environments
- **The performance assessment calculation should guide design choices (e.g. choice of steel grades dictated by optimization of corrosion resistance and thermal stability)**

Crevice Corrosion Growth Rate of 316L SS



Penetration Depth in 3000 years
8.2 cm

Long-term Initiation of Localized Corrosion
Alloy 825



TOTAL SYSTEM PERFORMANCE ASSESSMENT FOCUS TOPIC: INFILTRATION AND DEEP PERCOLATION

Participants
Stuart A. Stothoff and A.C. Bagtzoglou

N. Coleman (NRC)

Center for Nuclear Waste Regulatory Analyses

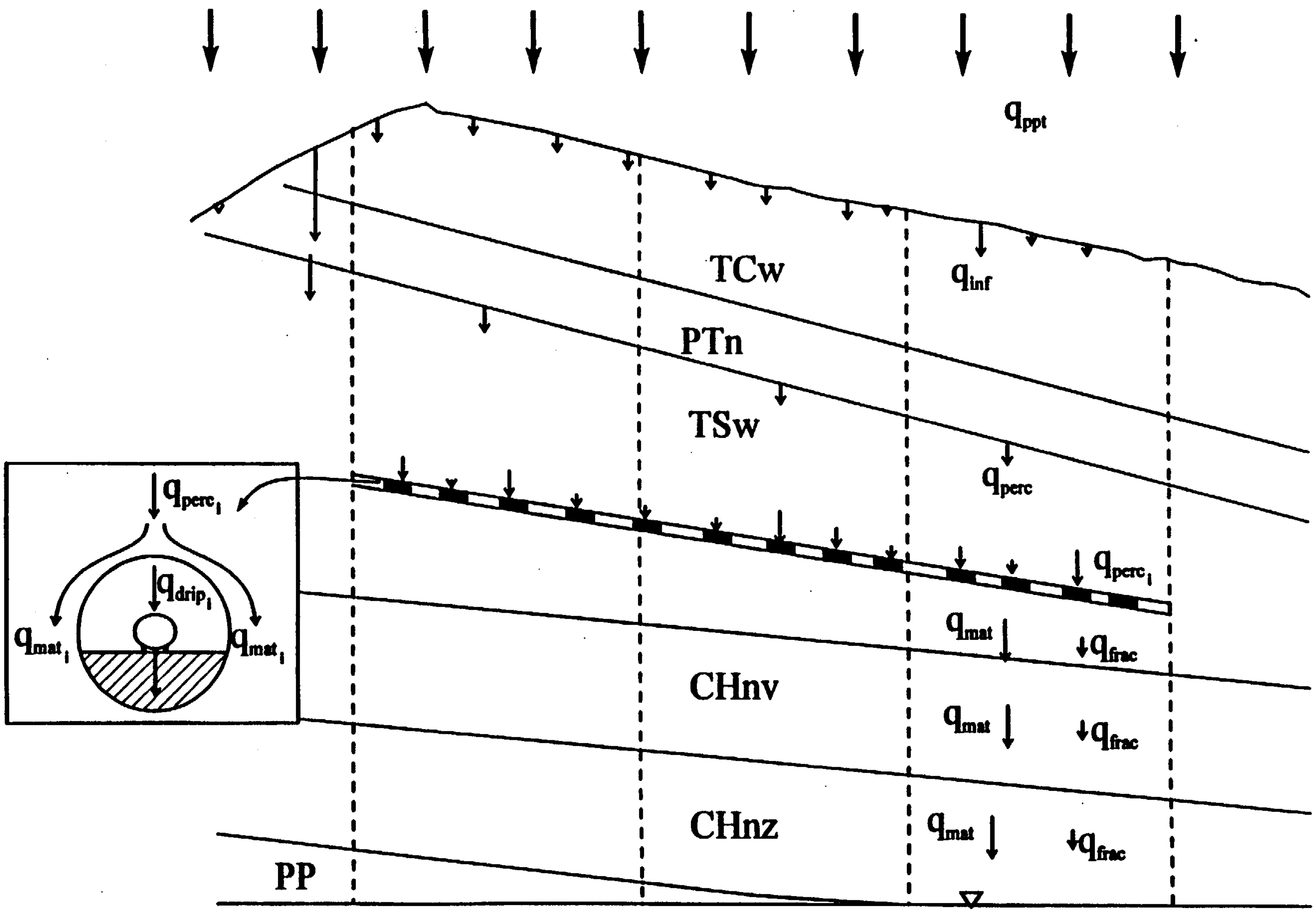
Presented by
Stuart A. Stothoff

May 22, 1996
Las Vegas, NV

MOTIVATION

- Infiltration And Deep Percolation Are Consistently Identified As Having The Most Impact on Repository Performance

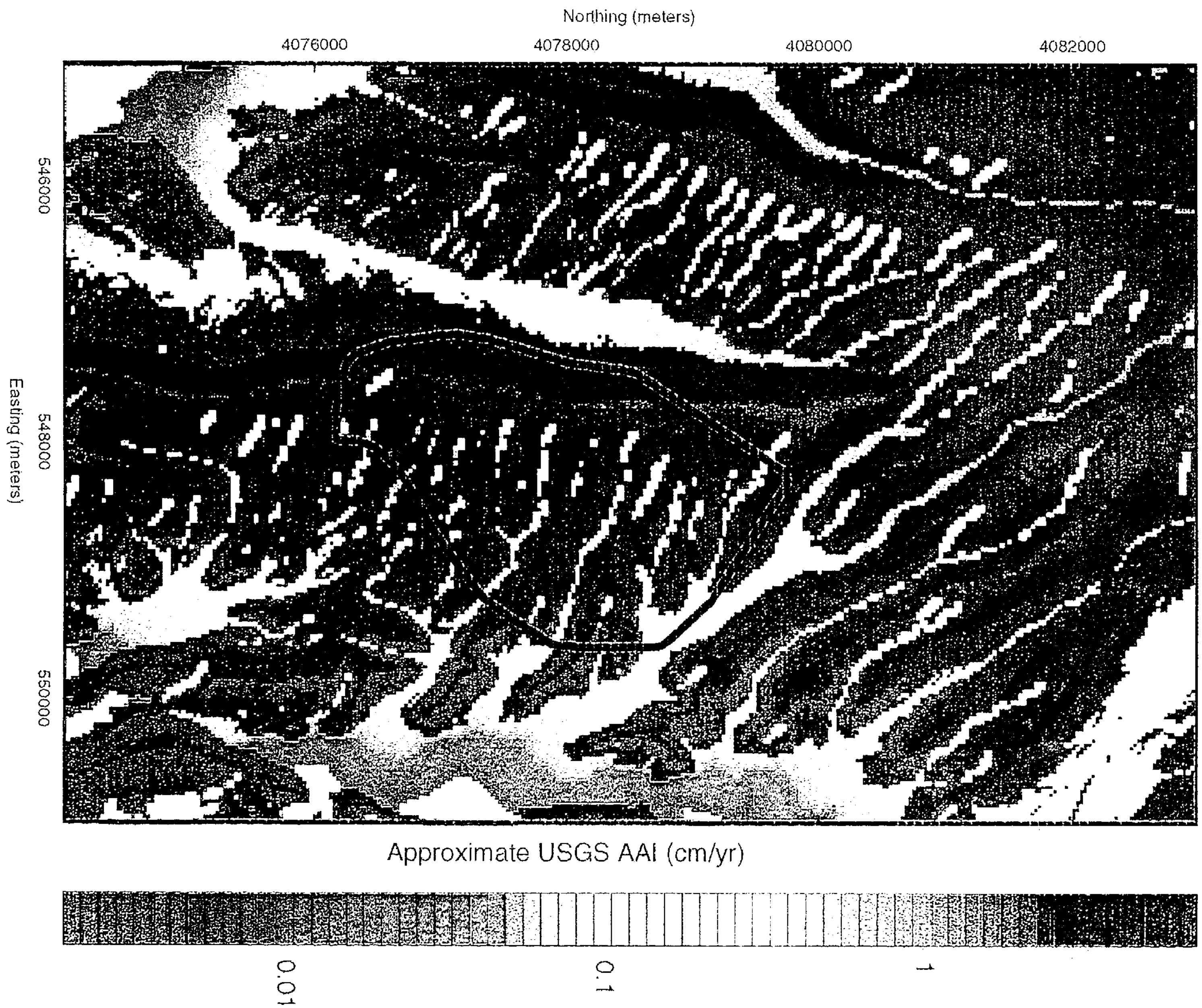
- Interpretation of TSPA-95 CCDF Results Required Analysis Of Flow Pathways And Travel Times



q_{ppt}
q_{inf}
TCw
PTn
TSw
q_{perc}
q_{perc_i}
q_{perc_i}
q_{drip_i}
q_{mat_i}
q_{mat_i}
q_{mat}
q_{frac}
CHnv
q_{mat}
q_{frac}
CHnz
q_{mat}
q_{frac}
PP

TABLE COMPARING TSPA-93 AND TSPA-95

INPUT	TSPA-93 (Wilson et al., 1994)	TSPA-95 (TRW, 1995)
Infiltration Rate	Dry q_{inf}=Exp(0.5 mm/yr) Wet q_{inf}=Exp(10 mm/yr)	q_{inf}=U(0.01, 0.05) mm/yr Flint and Flint (1994) Repository footprint only q_{inf}=U(0.05, 2) mm/yr Flint and Flint (1994) Weighted subregional average
Climate Variation	Dry/wet cycle w/100 ka repeats Dry water table rise=U(0, 10) m Wet water table rise=U(50, 120) m Duration of dry=U(0, 100) Ka within cycle ECM: Cycle steady-state flow Weeps: Generate weeps with climate change	Sawtooth w/100 ka period Multiple of q_{inf} at peak=U(1,5) Water table rise at peak=U(0,80) m
Percolation Process Model	ECM: TOSPAC (Dudley et al., 1988) Steady-state finite-difference Weeps: TOSPAC (Gauthier et al., 1992) Empirical	TOUGH2 (Pruess, 1987, 1991) with satiation ECM FEHM (Zyvoloski et al, 1995) for check
Percolation Abstraction	ECM: Hydraulic parameters sampled for each layer/column Weeps: Random spatial distribution and weeps properties	RIP (Golder, 1994) Abstracted parameters sampled each layer/column $\log(V_m)=U(\log(V_{min}), \log(V_{Max}))$ $\log(V_m)$, F_f correlation=−1 $V_f=(F_f\, q_{inf}) / \phi$
Lateral Flow	ECM: Lateral shedding Weeps: None	Tacitly in q_{inf} Magnitudes 1D checked vs. 2D and 3D
Geometry	5 1D columns (114 kW/acre) 8 1D columns (57 kW/acre)	6 1D columns (83 MTU/acre) 10 1D columns (25 MTU/acre)
Material Properties	Essentially Schenker et al., (1995)	Schenker et al., (1995) for matrix Constant fracture properties Fracture properties same in all layers
Thermal Effects	Percolation focused to unprotected portion of repository (source only) Isothermal flow and transport	No percolation with T>100°C Isothermal flow and transport
Stratigraphy	Random	Constant
UZ Transport Model	ECM: TOSPAC (Dudley et al., 1988) Finite-difference Weeps: None (SZ transport only)	RIP (Golder, 1994) Particle tracking Markovian matrix/fracture transition

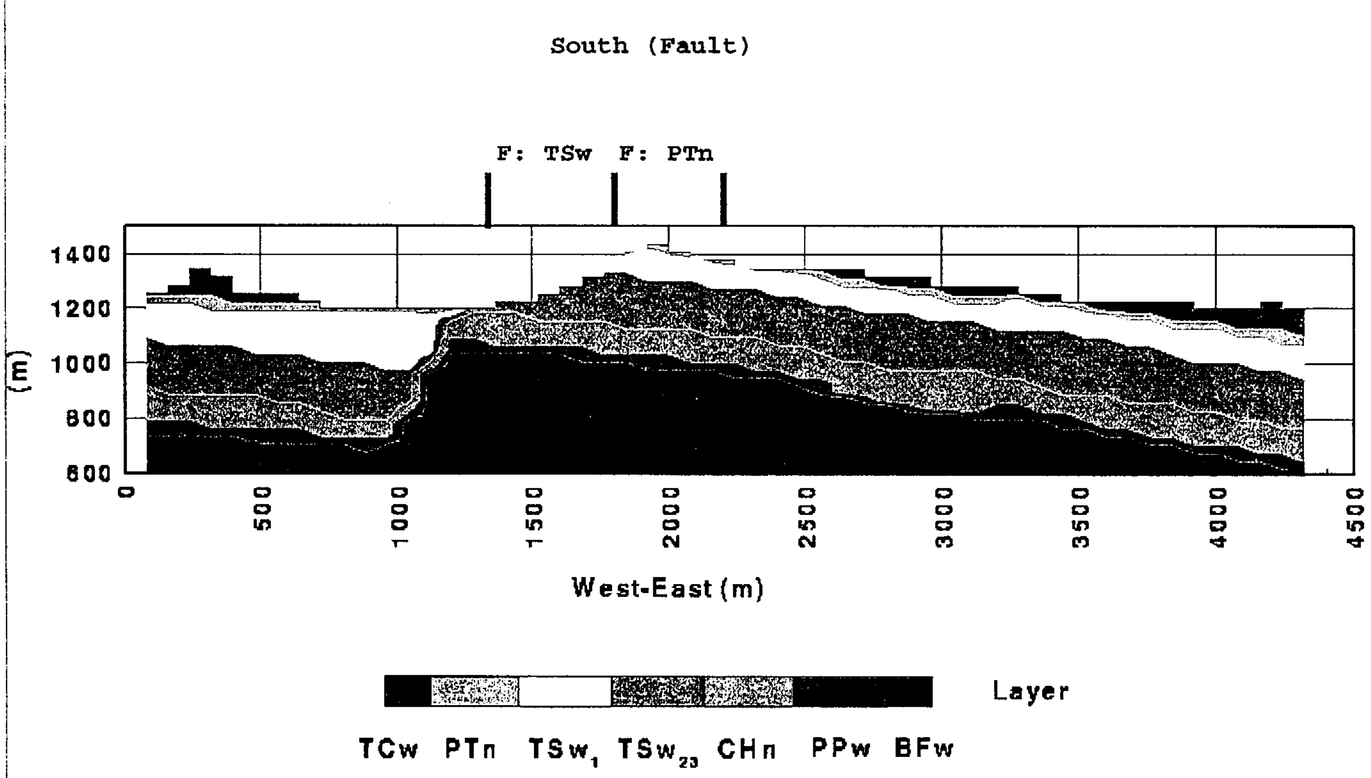

Northing (meters)
4076000
4078000
4080000
4082000
Easting (meters)
546000
548000
550000
Approximate USGS AAI (cm/yr)
0.01
0.1
1

AUDIT REVIEW OF INFILTRATION PERCOLATION

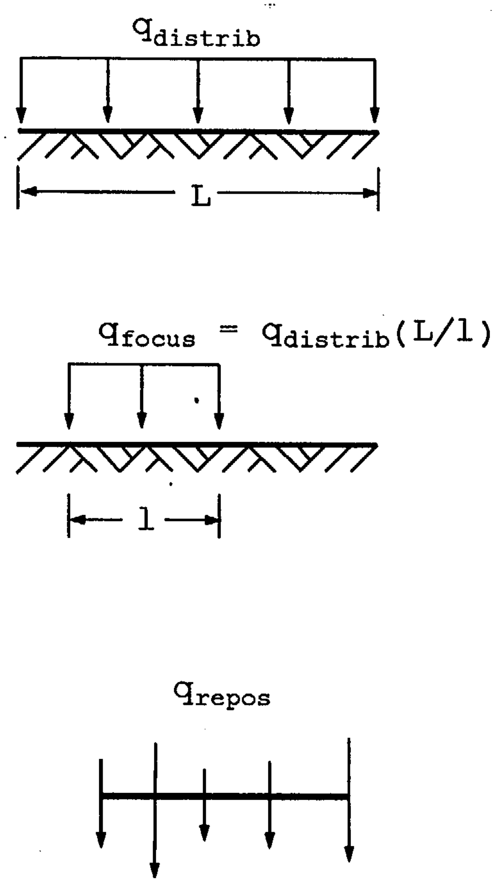
- TSPA-95 Modeling Approach Did Not Appear To Consider Impact Of Focused Infiltration
- Preliminary Analysis Was Conducted To Examine Relationship Between Infiltration And Deep Percolation
  - Comparison of focused and distributed infiltration
  - Evaluation of lateral diversion effects
  - Impact of faults

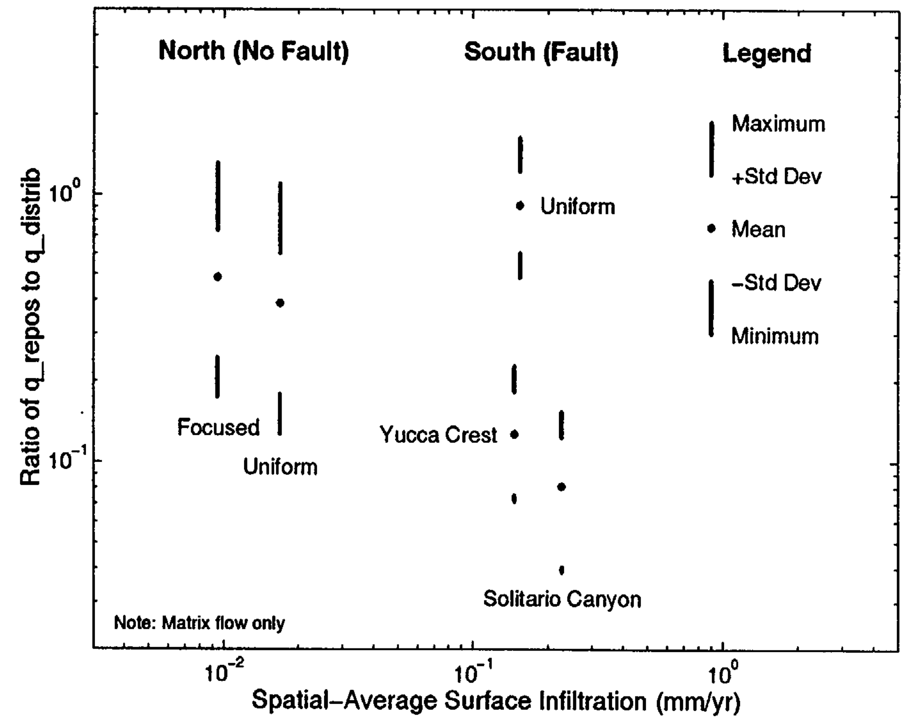
ANALYSIS OF DEEP PERCOLATION

- Two 2D EW Vertical Cross-Sections Considered:
  - North cross-section (small Solitario Canyon Fault offset)
  - South cross-section (large Solitario Canyon Fault offset)
- No Fractures Considered (Matrix-Only Flow)
- Faults Do Not Have Independent Hydraulic Properties
- No-Flow Side Boundaries


South (Fault)
F: TSw F: PTn
1400
1200
1000
800
600
(m)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
West-East (m)
Layer
TCw PTn TSw1 TSw23 CHn PPw BFw

IMPACT OF FOCUSED INFILTRATION ON RELATIVE FLUX AT THE REPOSITORY LEVEL





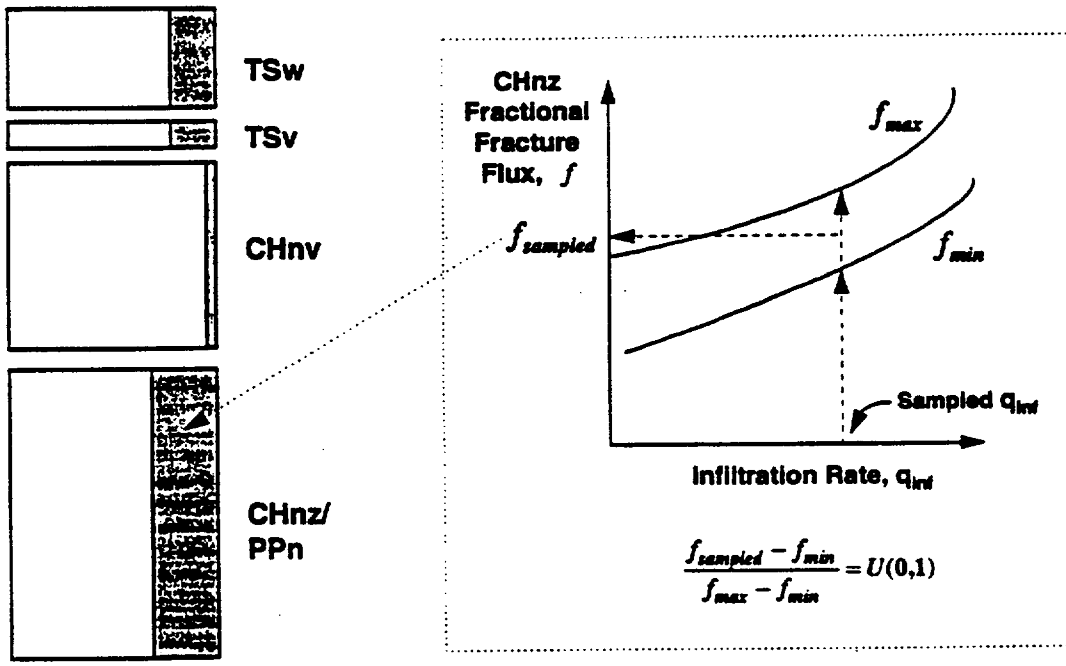
PRINCIPAL OBSERVATIONS

- Focused Shallow Infiltration Can Strongly Impact Fluxes At The Repository Horizon
- Lateral Flow May Be Greater With Increasing Infiltration
- More Work Is Required To Delineate Connections Between Shallow And Deep Percolation

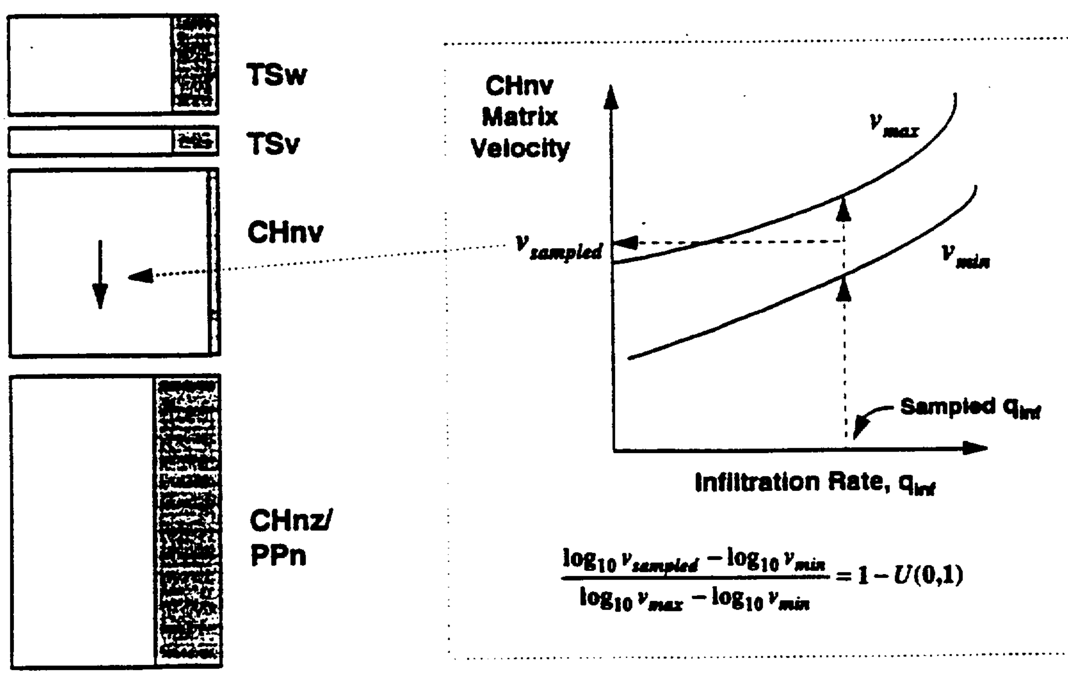
TPSA-95 PERCOLATION MODEL

- Use 10 Material-Property Realizations With:
  - 1 stratigraphic sequence
  - 2 ECM models
  - 10 infiltration rates
- For Each Infiltration Value (20 Realizations) And Layer:
  - Find minimum and maximum matrix velocity (V_m)
  - Find minimum and maximum fraction of flow in fractures (F_f)
  - Assume V_m is log-normal and F_f is uniform
  - Assume that log (V_m) and F_f are perfectly correlated
  - Assume fracture velocity is independent of saturation

How Much?
(Fractional-Fracture-Flow Process-Level Abstraction)



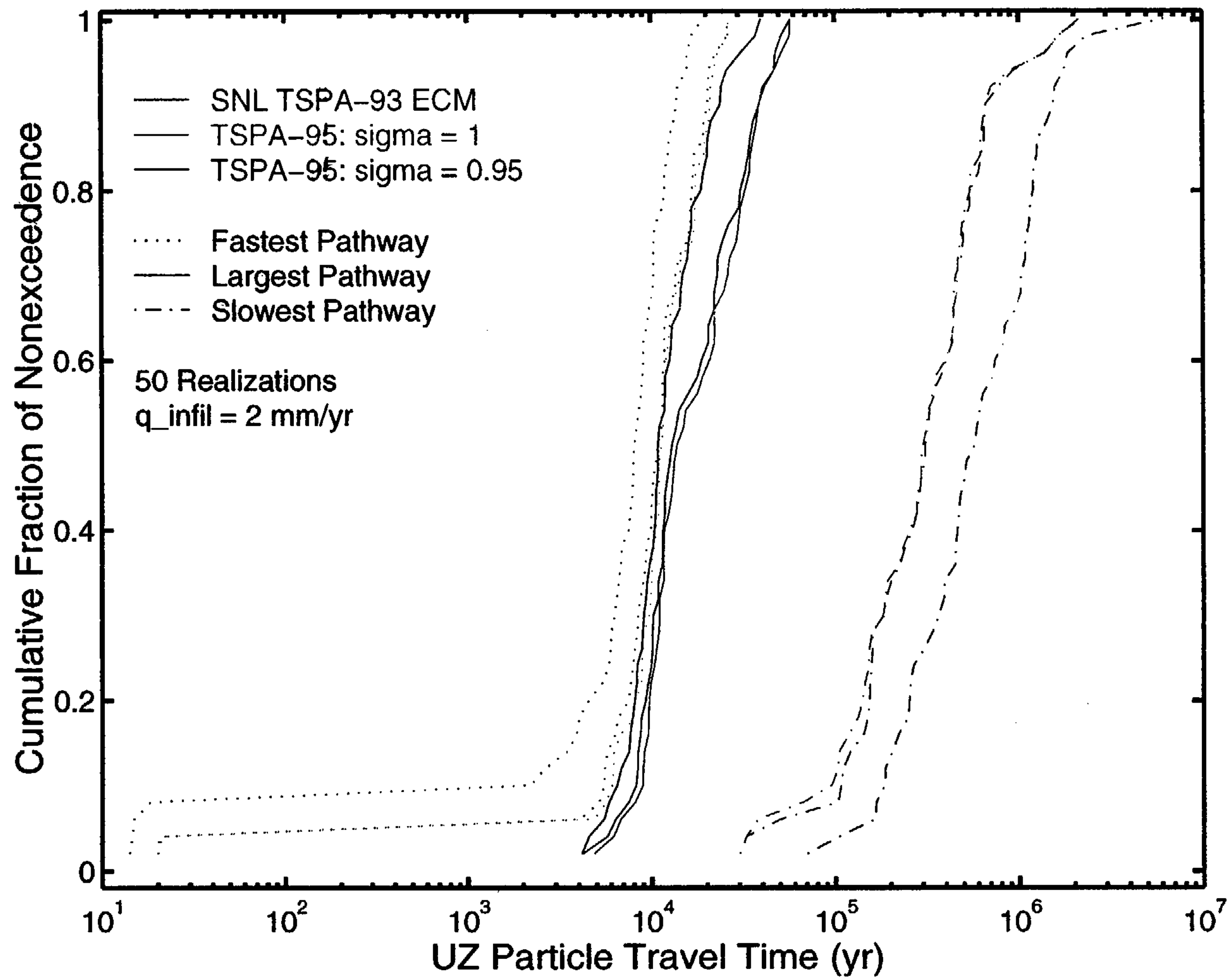
How Fast?
(Matrix-Velocity-Field Process-Level Abstraction)



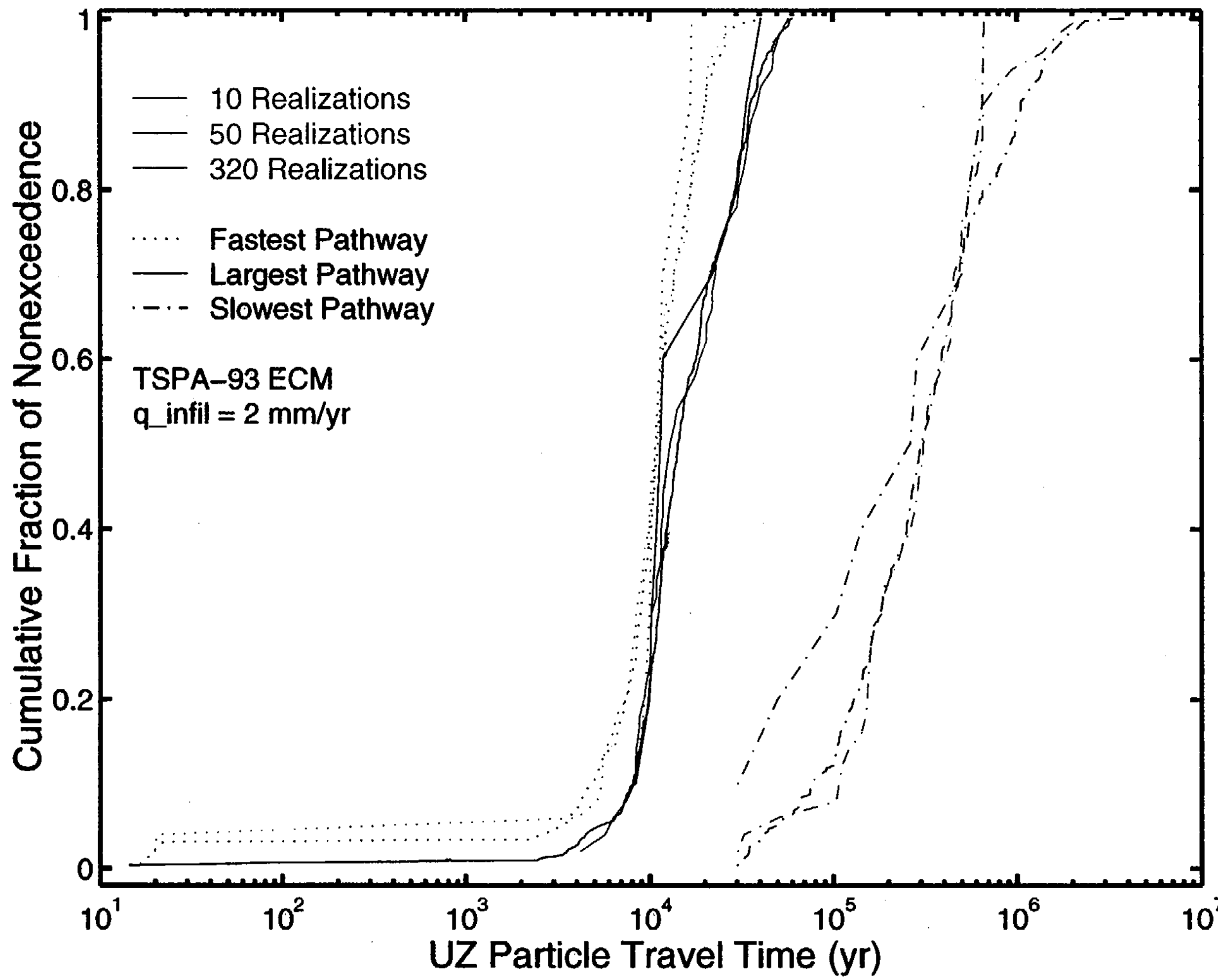
NRC/CNWRA REVIEW OF PERCOLATION MODEL

- Run 50 Material-Property Realizations:
  - 2 infiltration rates (0.01 and 2 mm/yr)
  - Follow TSPA-95 abstraction procedure
  - Use TSPA-95 ECMs plus SNL TSPA-93 ECM
  - Check particle travel-time estimates for ECMs and abstraction

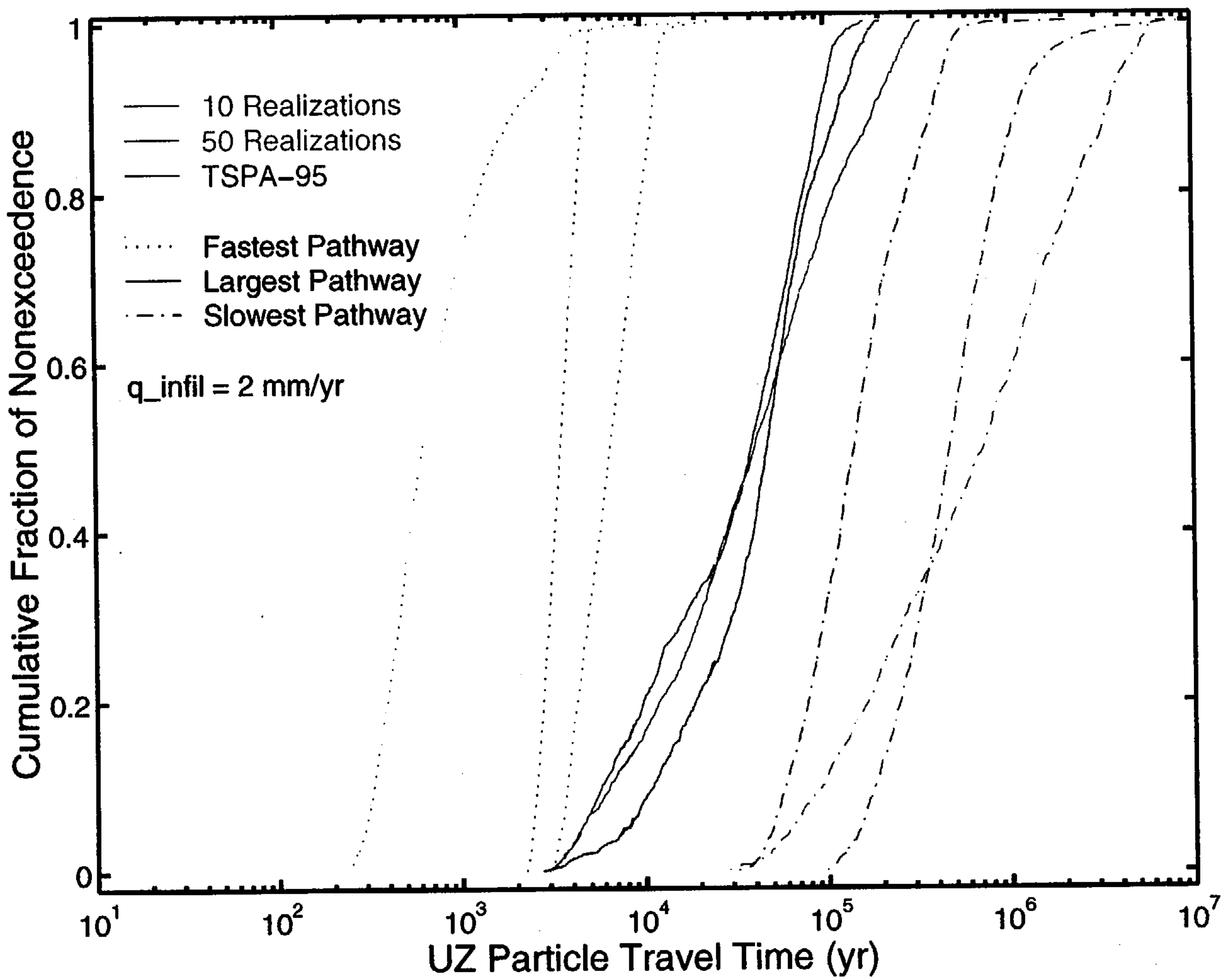
COMPARISON OF DOE PROCESS-LEVEL SIMULATIONS



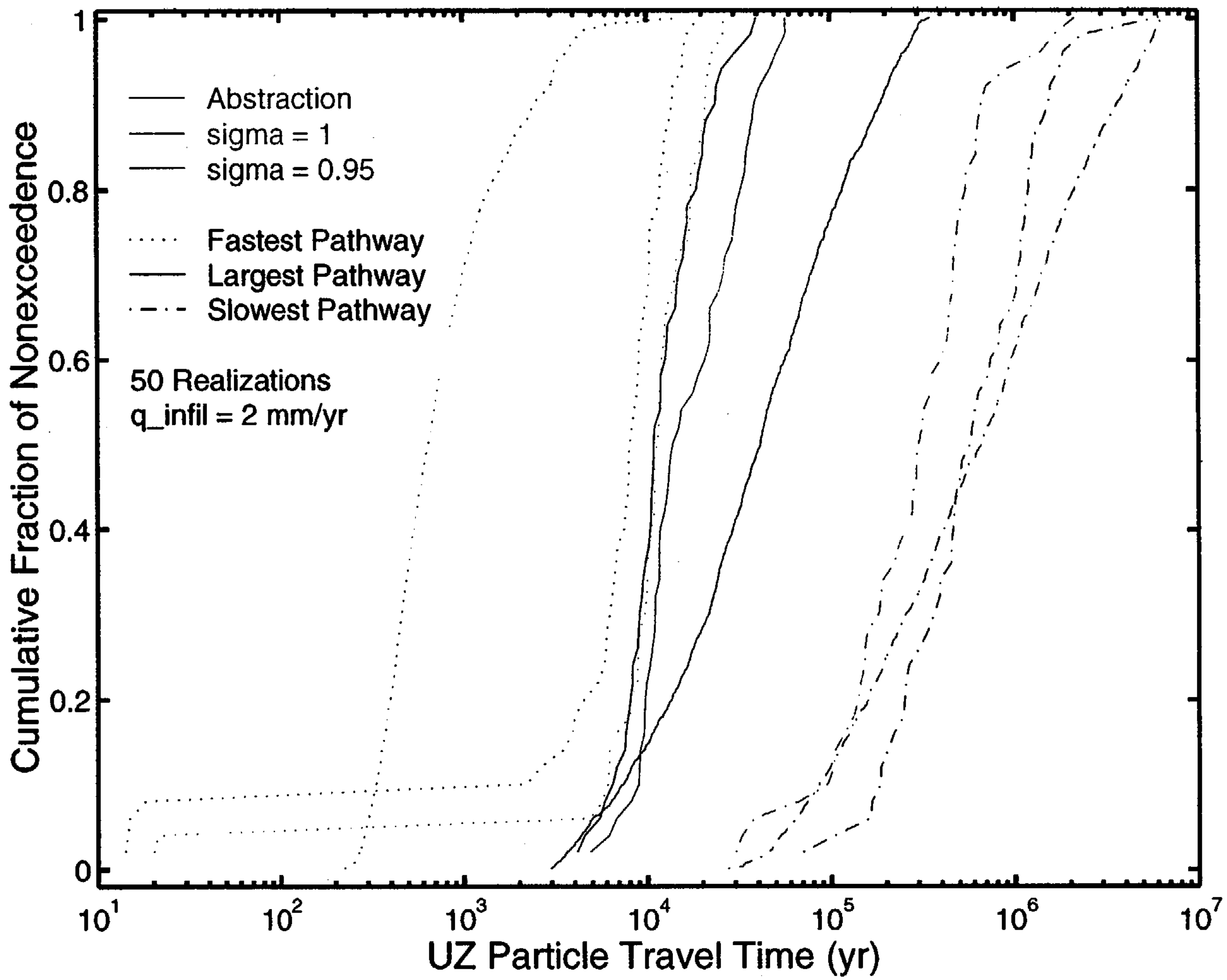
EFFECT OF NUMBER OF REALIZATIONS ON PROCESS-LEVEL PREDICTIONS



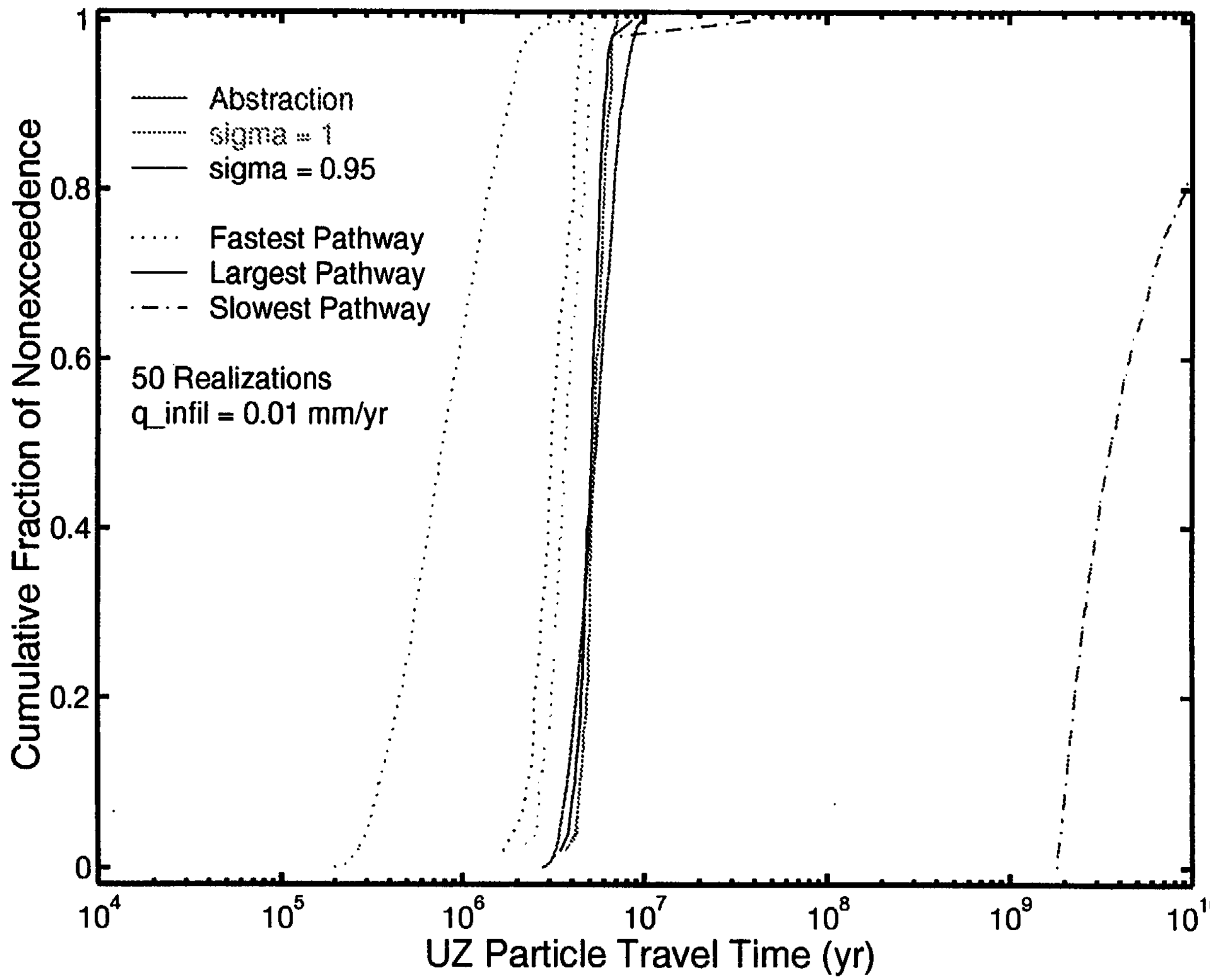
EFFECT OF NUMBER OF REALIZATIONS ON TSPA-95 ABSTRACTIONS



COMPARISON OF TSPA-95 PROCESS-LEVEL AND MODEL ABSTRACTION



COMPARISON OF TSPA-95 PROCESS-LEVEL AND MODEL ABSTRACTION



SUMMARY

- Saw-Tooth Representation Appears Appropriate For 10^6 But An Alternate Method May Be Needed For 10^4 Years
- Calculational Approach Appears To Underestimate Fracture Velocities
- Particle Travel Times In Fast Pathways May Be Nonconservative
- Unsaturated-Flow Abstraction Scheme May Be Nonconservative
- Number of Process-Level Realizations Performed May Be Insufficient

POINTS FOR DISCUSSION

- Calculational Results Should Be Updated Using More Recent USGS Estimates For Shallow Infiltration
- Shallow And Deep Percolation Studies Need To Be Related
- Focused Recharge And Lateral Flow Should Be Examined
- The Abstraction For Flow In UZ Should Be Re-Examined

TOTAL SYSTEM PERFORMANCE ASSESSMENT FOCUS TOPIC: DILUTION

Participants
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N. Coleman (NRC)

Center for Nuclear Waste Regulatory Analyses

Presented by
Robert G. Baca

May 22, 1996
Las Vegas, NV

MOTIVATION

- **Dilution is a Key Component of the DOE Waste Containment and Isolation Strategy**

- **Studies of Dilution Will Play A Major Role in Demonstration of Compliance With a Dose/Risk Standard**

DOE ANALYSIS APPROACH

- Two Calculational Models (Stirred Tank and Advection-Dispersion) Used to Estimate Dilution Factor (DF)
- Stirred Tank Model
  - Mixing Zone: 50 m (Assumed)
  - Darcy Flux: 2 m/yr (Unpublished Report)
  - DF a Function of q_{uz}
- Advection-Dispersion
  - Line Source
  - Dispersivity-Scale Coefficients
  - DF Function of q_{uz} and Path Length

NRC/CNWRA ANALYSIS APPROACH

- Two Calculational Models (Same as TSPA-95) Used to Calculate DF Estimates

- Stirred Tank Model

  - Mixing (Fracture) Zone: 10 m Estimated from USGS Reports*

  - Darcy Flux: $0.1 \leq q_{sz} \leq 1.0$ m/yr Estimated from Field Data**

  - DF a Function of q_{uz} (TSPA-95 and IPA Phase 2 Values)

- Advection-Dispersion Model

  - Line Source (Same as TSPA-95)

  - Constant Dispersivities ($5\ km$: $\alpha_T = 10m$; $30\ km$: $\alpha_T = 60\ m$)

  - DF Function of q_{uz} and path length

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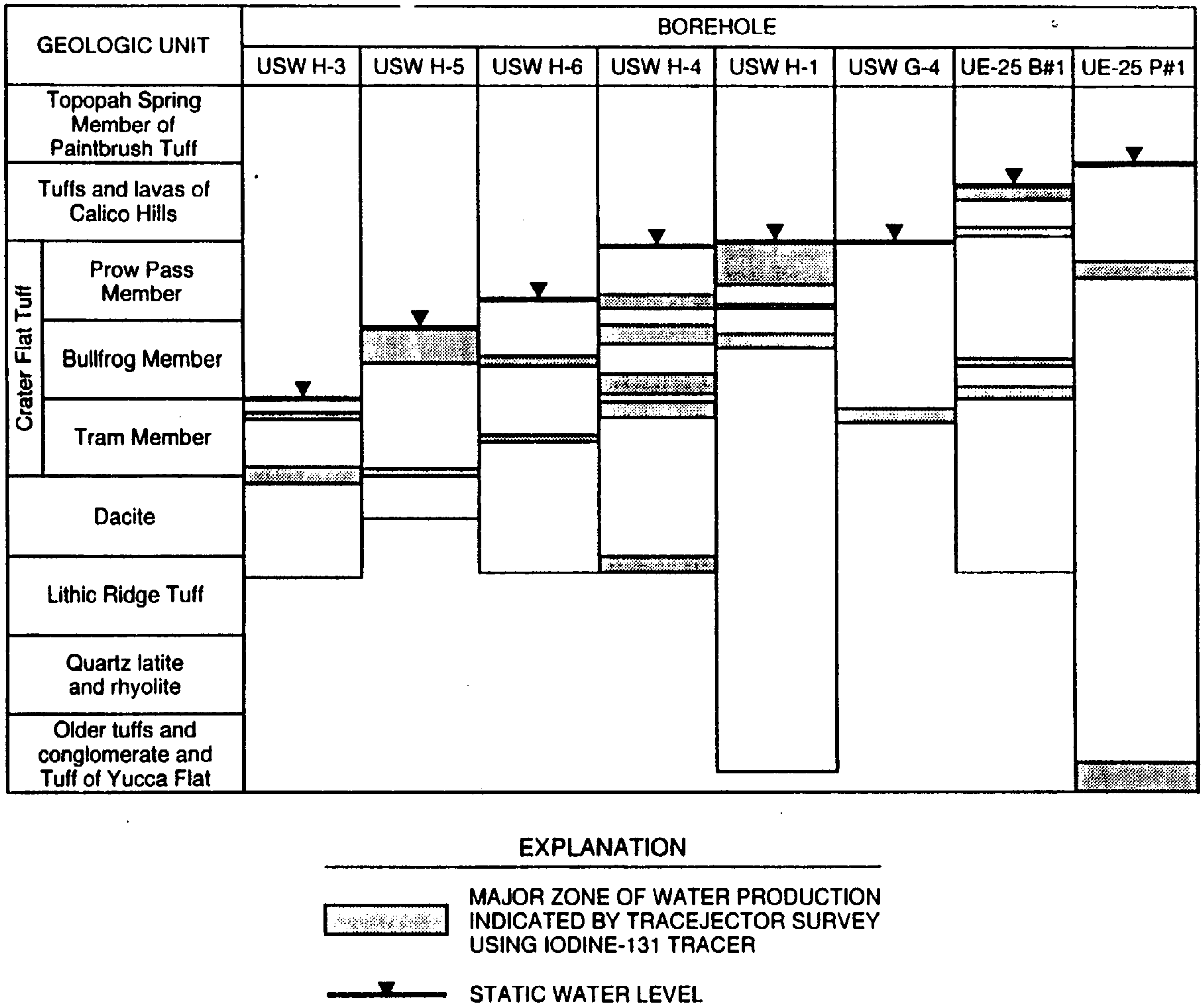
* Lobmeyer et al. (1983); Lahoud et al. (1984)
** Robison (1984); Wittwer et al. (1995)

WATER PRODUCING ZONES* NEAR YM



* from Geldon (1993)

SAMPLE BOREHOLE FLOWMETER TEST*

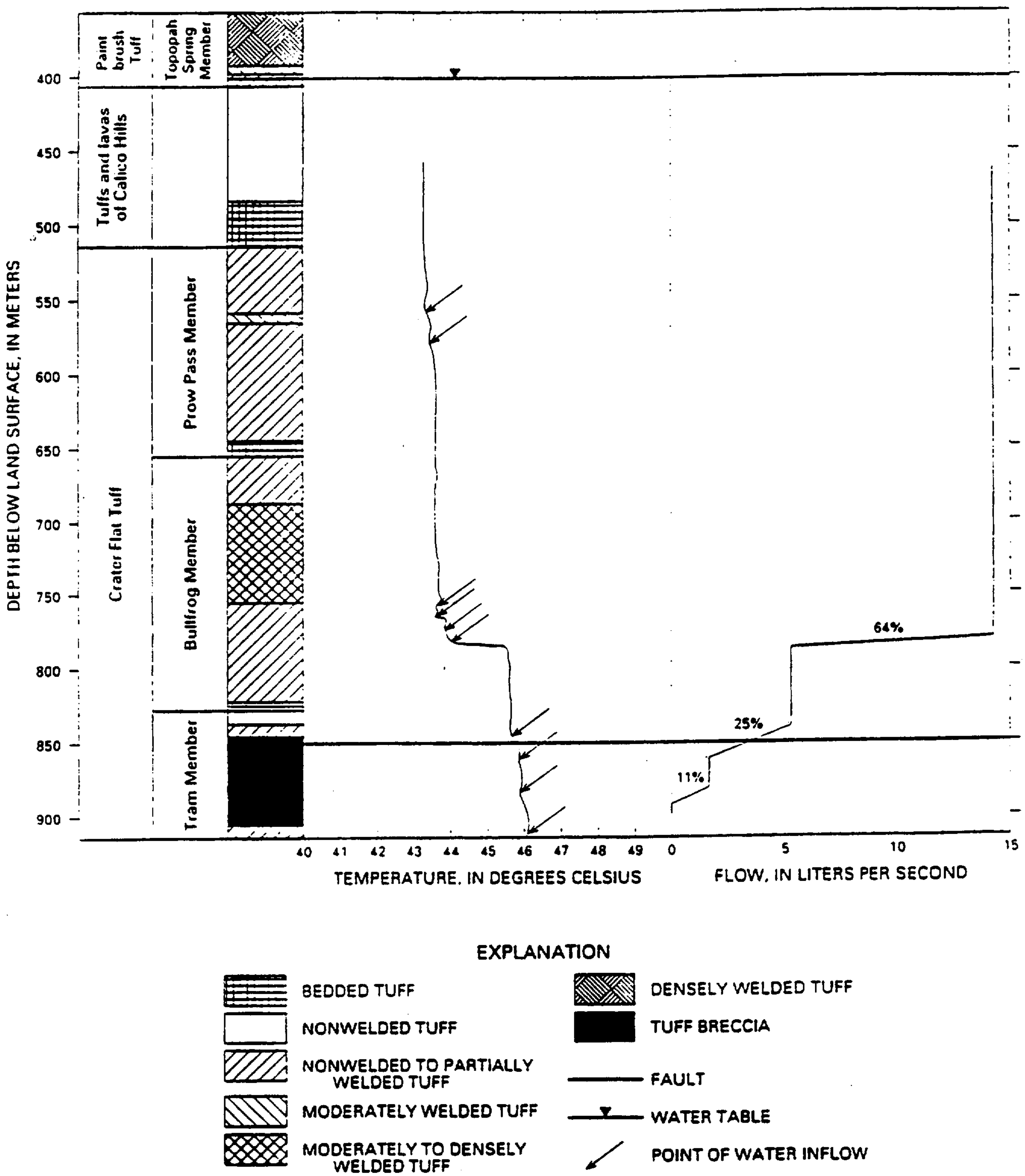


Figure 31.--Zones of ground-water production and points of inflow during pumping in borehole UE-25c #1, as indicated by temperature and tracejector data.

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* Geldon (1993)

STIRRED TANK MODEL

$$DF = \frac{q_{sz}}{q_{uz}} \frac{W_{rep}}{A_{rep}} h$$

$$W_{rep}/A_{rep} = 10^{-2}$$
$$h = 10\ m$$

TSPA-95 Estimates:

$800 \leq DF \leq 3.3 \times 10^4$

Audit Review Estimates:

$3.3 \leq DF \leq 3.3 \times 10^2$ (TSPA-95 q_{uz}, conservative q_{sz})

$2 \leq DF \leq 20$ (IPA Phase 2 q_{uz}, conservative q_{sz})

ADVECTION-DISPERSION MODEL

$$DF = \frac{q_{sz}}{q_{uz}} \frac{L}{A_{rep}} \frac{\sqrt{\pi \alpha_T x}}{erf\left\{\frac{L}{4\sqrt{\alpha_T x}}\right\}}$$

$L = 4 \times 10^3$ m (from TSPA-95)

$A_{rep} = 4 \times 10^5$ m^2 (from TSPA-95)

TSPA-95 Estimates:

q_{uz} (m/yr)	Dilution Factors	
	5 km	30 km
1.25×10^{-3}	4.5×10^3	3.1×10^4
3.0×10^{-5}	1.9×10^5	1.3×10^6

ADVECTION-DISPERSION MODEL

Audit Review Estimates (TSPA-95 q_{uz} with Conservative q_{sz} and α_T)

q_{uz} (m/yr)	Dilution Factors	
	5 km	30 km
1.25×10^{-3}	9.5×10^2	8×10^3
3.0×10^{-5}	4×10^4	3.4×10^5

Audit Review Estimates (IPA Phase 2 q_{uz} with Conservative q_{sz} and α_T)

q_{uz} (m/yr)	Dilution Factors	
	5 km	30 km
1×10^{-2}	1.2×10^2	1.7×10^3
5×10^{-3}	2.4×10^2	3.4×10^3

PREVIOUS DOE MODELING STUDIES

TSPA-93 TRANSPORT CALCULATIONS*

- **Three-Dimensional Groundwater Model Calibrated to Available Field Data**
- **Transport of Conservative Solute Modeled to Calculate Plume Spread and Breakthrough Curves at 5 km**
- **Simulation Results suggest $5 < DF < 10$**

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* Wilson et al. (1994)

REGIONAL GROUNDWATER HYDROCHEMISTRY DATA

HYDROCHEMICAL EVIDENCE

- Persistence of Vein Carbonates, in Contrast with Current Chemical Undersaturation of Groundwaters with Respect to Calcite, Suggests Channeling of Flow (Murphy, 1995)

- Hydrochemical Isotope Signatures (δD, ^{14}C) and Bulk Chemistry Persist over Large Distances (tens of km), Suggesting limits to Mixing between Regional Aquifers (Winograd and Pearson, 1976)

SUMMARY

STATEMENT OF ISSUES

- Dilution Factor Calculations Presented on TSPA-95 May Lack Defensibility Because:
  - Available Hydrogeologic Data Not Used in Calculations
  - Assumptions Used in Analytical Models Not Conservative or Bounding
  - Calculations Do Not Build Upon Previous DOE Modeling Studies
  - Hydrochemistry Data Not used to Confirm Model Calculations
- Analysis Did Not Consider Groundwater Withdrawals by the Critical Group (e.g., Amargosa Farms) which May Produce Significant Mixing and Dilution

POINTS FOR DISCUSSION

- Developing Defensible Estimates For Dilution Factors:
  - Available Hydrogeologic Data (e.g., Wittwer et al., 1995, USGS Reports)
  - Utilize Field Tracer Test Data (e.g., C-Well Complex)
  - Build on Existing Site Scale (e.g., Wilson et al., 1994) and Regional Scale Modeling Studies (e.g., Czarnecki, 1985)
  - Utilize Available Geochemistry Data to Support Analysis of Dilution
- Conduct Regional Scale Modeling Studies to Assess Dilution resulting from Mixing Induced by Water Use in the Amargosa Valley

TOTAL SYSTEM PERFORMANCE ASSESSMENT FOCUS TOPIC: TSPA ABSTRACTION

Participants
S. Mohanty, S. Stothoff, R.G. Baca, J.C. Walton

R. Wescott, T. McCartin (NRC)

Center for Nuclear Waste Regulatory Analyses

Presented by
Robert G. Baca

May 22, 1996
Las Vegas, NV

DOE ANALYSIS APPROACH

- The RIP Code is Used to Estimate Total Release and Peak Dose

- Model Abstractions Used to Represent Repository Subsystems

  — EBS: Waste Package Containment and Release for In-drift Emplacement

  — Site Subsystem: Matrix-Fracture Flow (Response Curve) and Transport (Markovian-Particle Method)

- Only Undisturbed Performance Considered in TSPA-95

- Total System Performance Computed Assuming Various Combinations of Design and Site Behavior for 10^4 and 10^6 yrs

NRC/CNWRA AUDIT REVIEW APPROACH

- The TPA Code Used to Estimate CCDF for Total Release

- Model Abstractions Used to Represent Repository Subsystems and Coupled Effects

  - EBS: New Module in Development (EBSPAC)

  - Site Subsystem: Matrix-Fracture Flow (Rule-Based) and Transport (Advection-Dispersion)

- Only One Case Considered: 10^4 yr, 83 MTU/acre, Backfill, and High Infiltration Range (0.5-2.0 mm/yr)

NRC/CNWRA AUDIT REVIEW APPROACH

- Assumed TSPA-95 Container Lifetime Curve (Fig 5.7-10a, p.5-72)

- Performed TPA Code Runs for Two Cases:

  (i) TSPA-95 Input Assumptions Approximately Equivalent

  (ii) IPA Phase 2* Input Assumptions

- Impact of Site Subsystem Abstractions Evaluated

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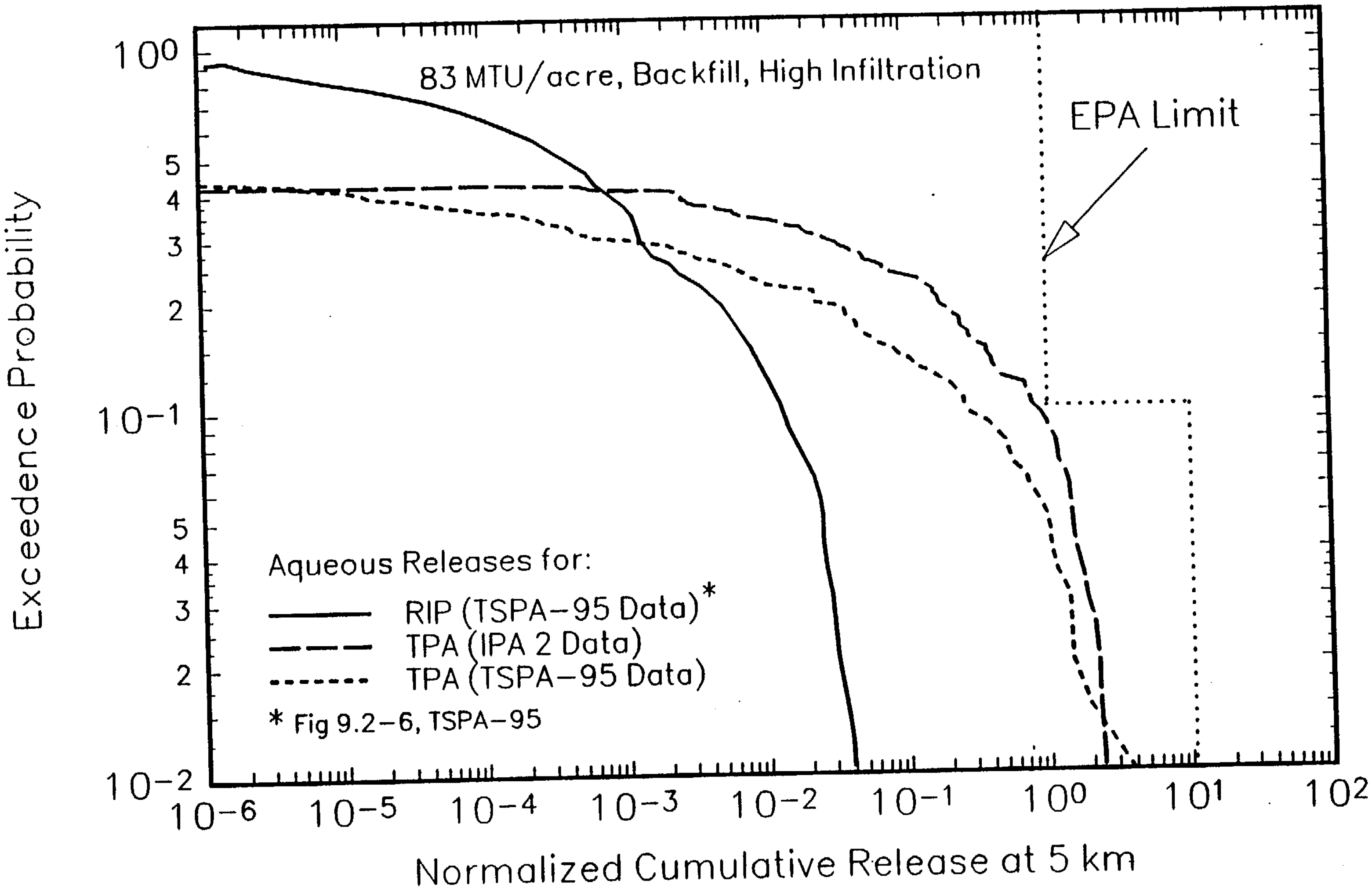
* NUREG-1464

COMPARISON OF CCDFs FOR CUMULATIVE RELEASE



POSSIBLE EXPLANATIONS OF CONTRASTING RESULTS

- Particle Travel Times in Unsaturated Zone May be Significantly Different

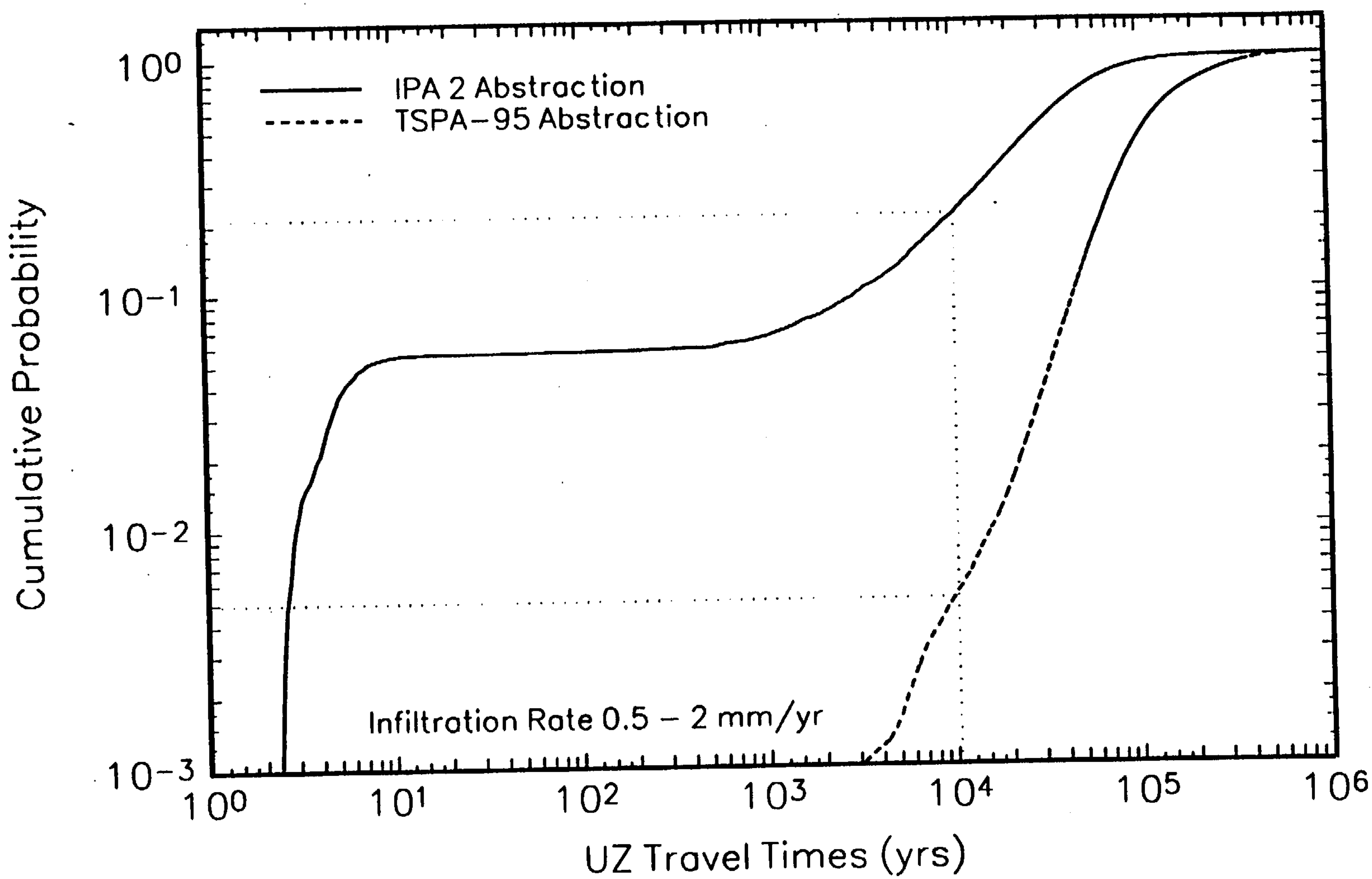
  - Flow Matrix-Fracture Interaction (Rule-based Versus Response curve)

  - Radionuclide Transport Abstractions (Advection-dispersion Versus Markovian-Particle Method

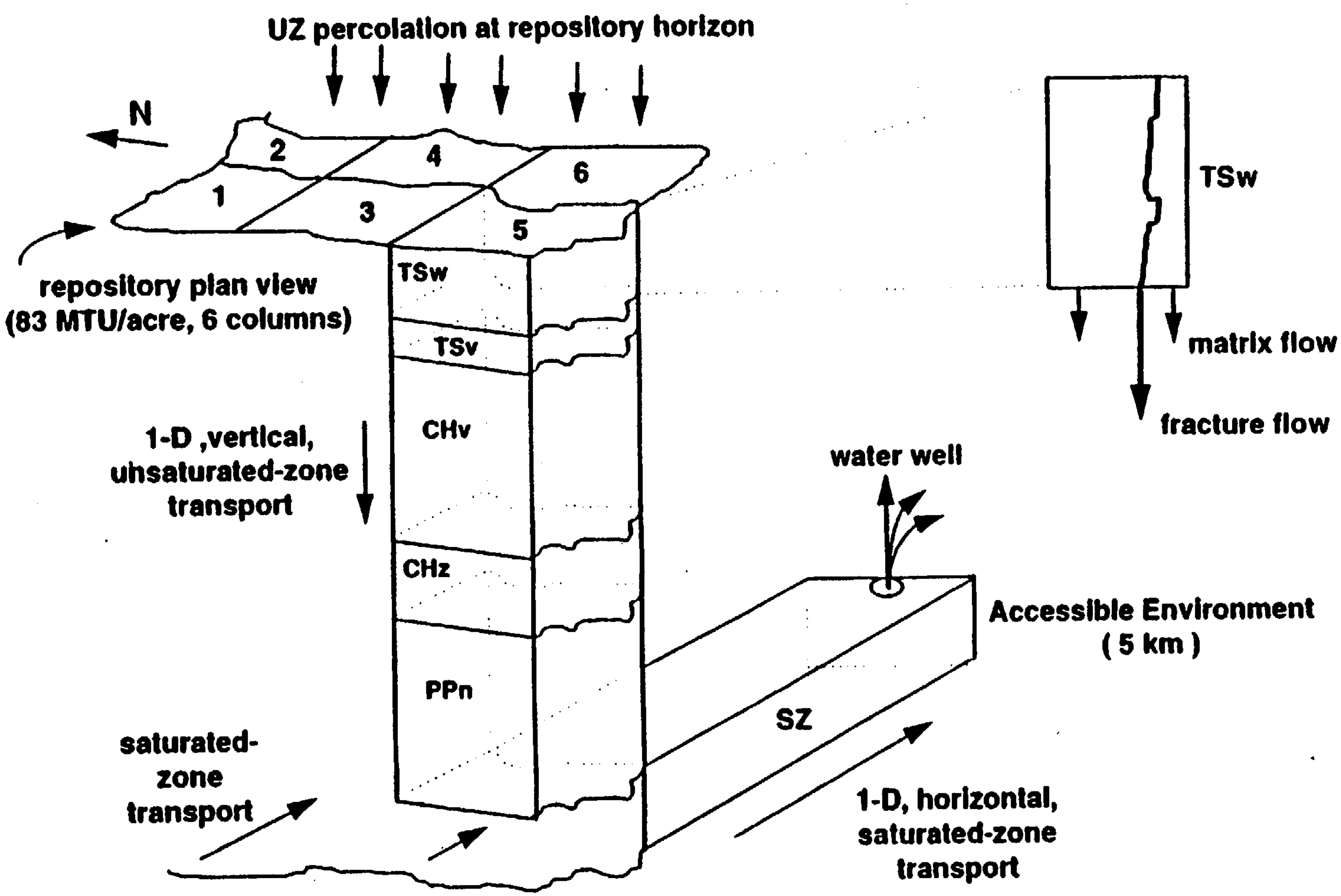
- Representations of Hydrostratigraphy may be Distinct

- Assumptions Regarding Container Failures in Subzones may be Different

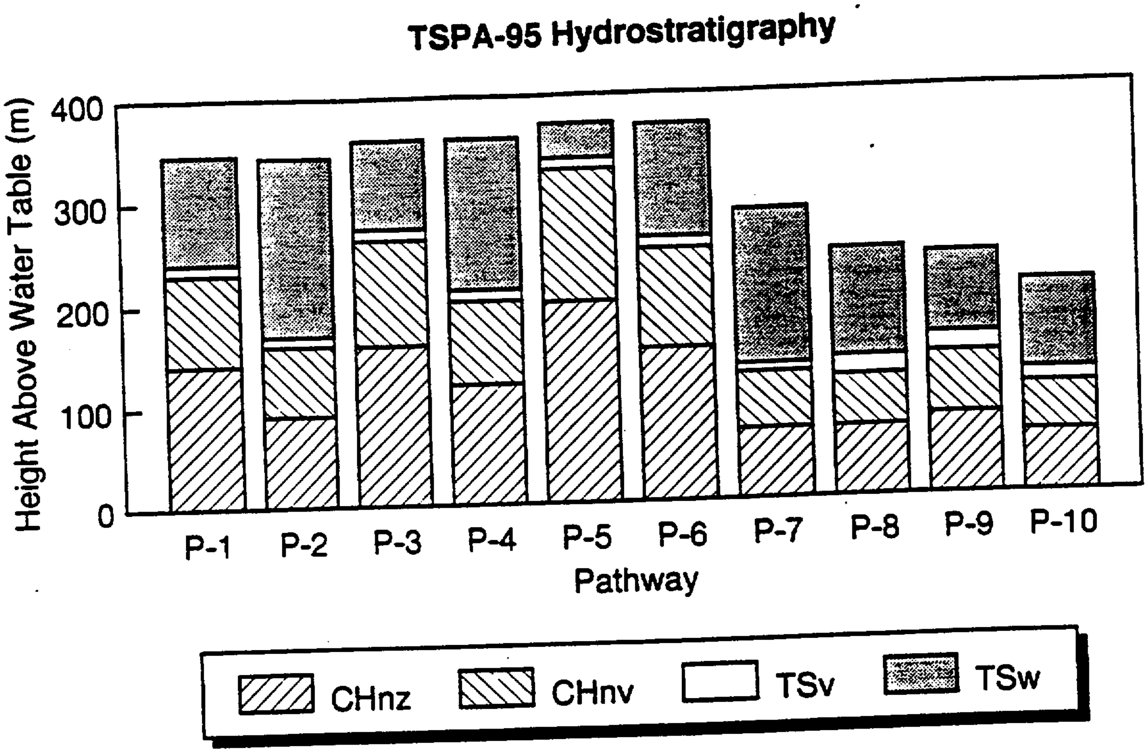
COMPARISON OF PARTICLE TRAVEL-TIME CDFs

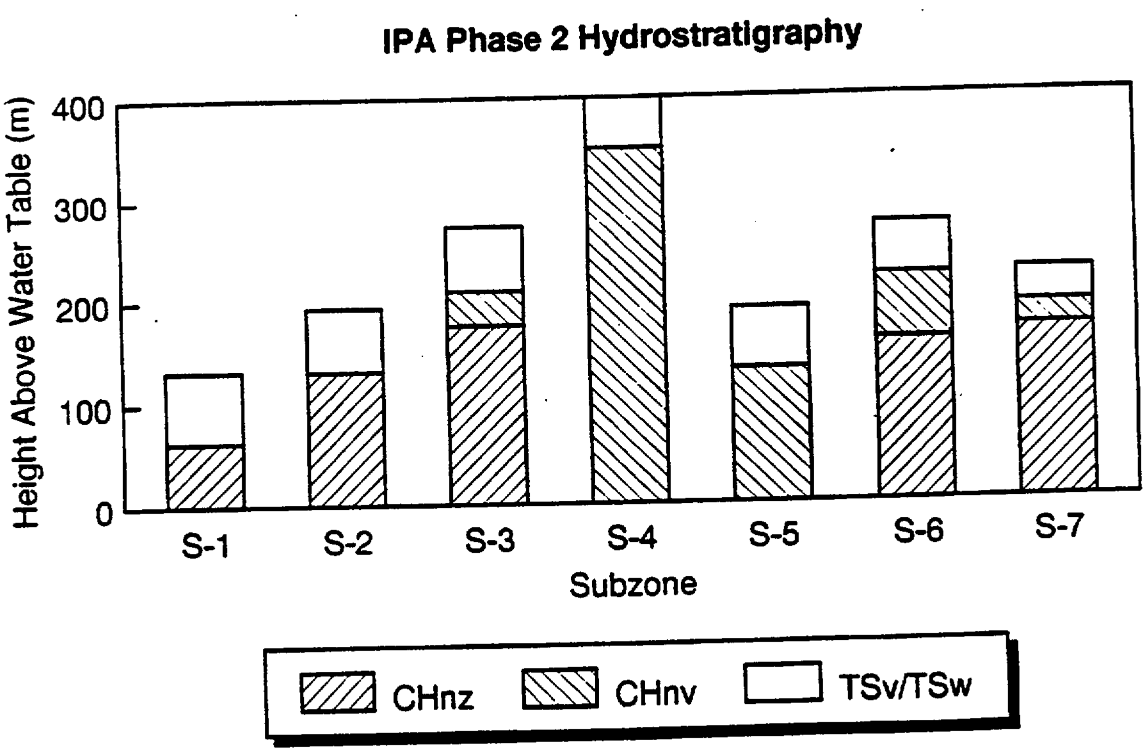


TSPA-95 REPOSITORY/UNSATURATED ZONE MODEL



COMPARISON OF HYDROSTRATIGRAPHIC MODELS





SUMMARY

- CCDF Results Were Not Sufficiently Explained in Terms of Basic Physical Factors

- TSPA-95 Site Subsystem Abstraction Appears to be Optimistic, i.e., Does Not Reflect Significant Transport Along Well Interconnected Fractures

POINTS FOR DISCUSSION

- **Use Intermediate and CCDF Sensitivity Results to Enhance Physical Understanding TSPA Calculations**
    - **CDFs for Particle Travel Times (Overall and by Pathway)**
    - **CDFs for Container Lifetime (by Repository Zone)**
- **Re-examine Appropriateness of Site Subsystem Abstraction Particularly With Regards to Transport along Fractures**

DOE-NRC TSPA TECHNICAL EXCHANGE
WORKING GROUP BREAKOUT SESSIONS: DISCUSSION TOPICS

WORKING GROUP 1: Container Life and Source Term/Thermal Effects

- Temperature and Relative Humidity
  - Conceptual models addressing heat and relative humidity
  - Differences between TSPA-1995 and CNWRA values for initial temperature and effective conductivity
    - Radiative transfer and effective conductivity
    - Temperature asperity at 10 years (assumed conductivity)
    - Relative v. absolute humidity
  - Computational problems associated with high infiltration
  - Waste package characteristics at repository edge (periphery)
    - Heterogeneity of waste packages
    - Boundary conditions (P, S, T) for 2- and 3-D models
    - Treatment of fracture flow
    - Heat conduction domination of peak temperatures. Is conduction the only code appropriate? Good enough?
- Container Life and Source Term
  - Process for determining importance to performance
    - How will NRC determine if embrittlement is important? What is its sensitivity?
    - Has DOE exhausted container failure scenarios?

- Waste package degradation
  - How to extrapolate from short-term to long-term corrosion data (interfering corrosion products)
  - Galvanic protection
  - Use of extreme value or normal distribution for pitting calculations
  - Temperature limits on progression of embrittlement
  - Balance of materials used to address thermal load v. embrittlement
  - Critical relative humidity v. temperature
  - Critical relative humidity v. near-field environment/chemistry
  - Pit growth rate as a function of environment
- Near-field environment
  - Alternating wet/dry environment and corrosion products
  - Characterization of dripping in alternating wet/dry regime
  - Assumptions for near-field chemistry? Sufficient range?
- Waste dissolution/Near-field/Source term
  - Effect of corrosion products on sorption, source term
  - Relationship between colloidal size and transport potential
  - Pulse v. Long-term (Tc/I): dry oxidation acceleration
  - Colloid question: C-well results?
  - Zircalloy

WORKING GROUP 2: Infiltration and Deep Percolation/Dilution/TSPA

- Abstraction
  - Markovian calculations in TSPA-1995
  - Model dependency on conclusions, assumptions
  - Limit of response curve
  - Importance of drift-scale calculations
  - Correlation between units spatially and vertically. Is there any? Is the abstraction in TSPA-1995 correct in its treatment?
- Flow
  - Fracture properties
  - Areas of focused infiltration: importance and derivation
  - Climate change over 10,000 years
  - Are TSPA-1995 fracture velocities incorrect?
  - Importance of lateral flow
  - Fracture-matrix partitioning
- Dilution
  - Basis/rationale for mixing depth assumed in TSPA-1995
  - Basis/rationale for average flux value (.1m) used by NRC v. others (.2m)
- TSPA Abstractions
  - Differences between container failure times and release times
  - Rule-based method for fracture-matrix code
  - CCDF charts: NRC results cover broader range. What is the difference between the two models that could account for the discrepancy? How to account for the geometric differences in the curve?

TRACE OF NP237 DOSE CALCULATION

(Analysis performed by Tim McCartin)

- Trace of two realizations which used expected values for sampled parameters
- Low infiltration realization (.03 mm/yr)
- High infiltration realization (1.25 mm/yr)

TRACE OF NP237 DOSE CALCULATION (contd.)

- Trace of calculations included:
- Flow contacting waste
- Release rate based on solubility
- Concentration in aquifer
- Drinking water Dose
- Comparison with TSPA 95 results

FLOW CONTACTING WASTE

Flow contacting waste = (fracture drip flux) * (# of packages with drips) * capture area per package

Fracture drip flux (low infil) = .0025 mm/yr
Fracture drip flux (high infil) = .70 mm/yr

# of packages (low infil) = .06 * 6468 = 388
# of packages (high infil) = .50 * 6468 = 3234

FLOW CONTACTING WASTE (contd.)

Capture area per package = 41 m^2

Flow contacting waste (low infil) = .0025 * 388 * 41 = .04 m^3/yr

Flow contacting waste (high infil) = .50 * 3234 *41 = 92.8 m^3/yr

RELEASE RATE BASED ON SOLUBILITY

Mean value for ^{237}Np Solubility Limit: 34 g/m^3

34 g/m^3 * 7.05 X 10^{-4} Ci/g = .024 Ci/m^3

Release (low infil) = .024 ci/m^3 * .04 m^3/yr = 9.6 X 10^{-4} Ci/yr

Release (high infil) = .024 Ci/m^3 * 92.8 m^3/yr = 2.2 Ci/yr

DETERMINATION OF DRINKING WATER DOSE

Dilution Volume = 400,000 m^3/yr

Np237 Dose Conversion Factor = 3.2 X 10^9 mrem/yr per Ci/m^3

Np237 Dose (low infil) = (9.6 X 10^{-4} / 400,000) * 3.2 X 10^9 mrem/yr per Ci/m^3 = 7.5 mrem/yr

Np237 Dose (high infil) = (2.2 / 400,000) * 3.2 X 10^9 mrem/yr per Ci/m^3 = 17,000 mrem/yr

TSPA 95 Np237 DRINKING WATER DOSE

Figure 9.3-12 (page 9-67):

Np237 Dose (low infil) = .0001 mrem/yr

Np237 Dose (high infil) = 200-300 mrem/yr

REASON(S) FOR DIFFERENCE

At 2 Ci/yr, total pulse of Np237 should last no more than 35,000 years (based on total inventory of 70,000 Ci)

Figure 9.3-12 shows the Np Concentration in the Aquifer being maintained for over one million years.

Random path length abstraction (7.4.4 and 7.4.5) appears to be possible explanation.

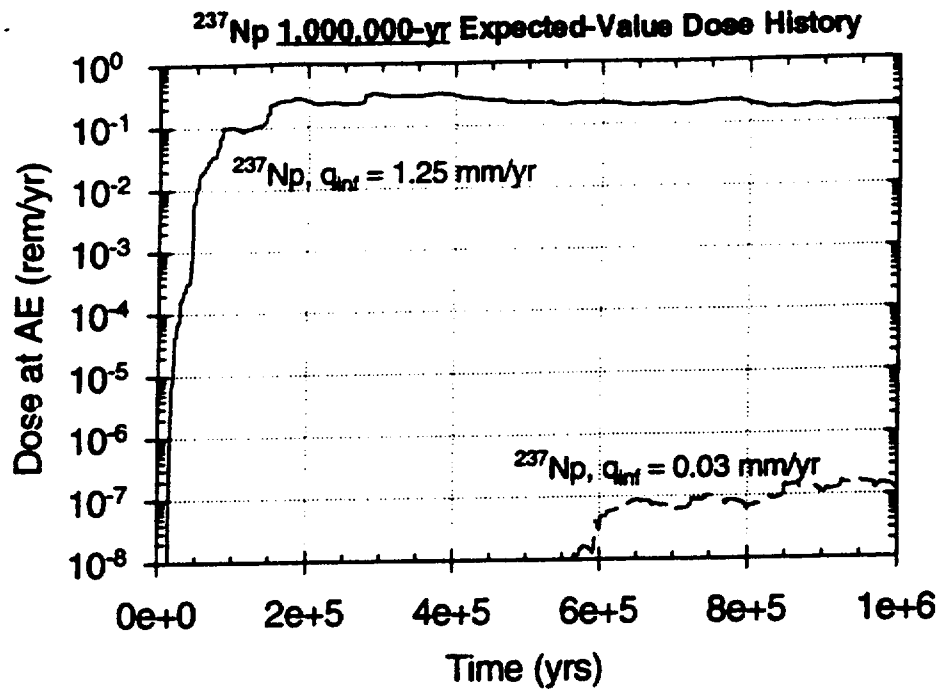


Figure 9.3-12 Expected-value dose history for ^{237}Np. 1,000,000 years, infiltration rate comparison: "high" (q_{inf} = 1.25 mm/yr) versus "low" (q_{inf} = 0.03 mm/yr) infiltration, 83 MTU/acre, backfill, cyclical-q_{inf} climate model.

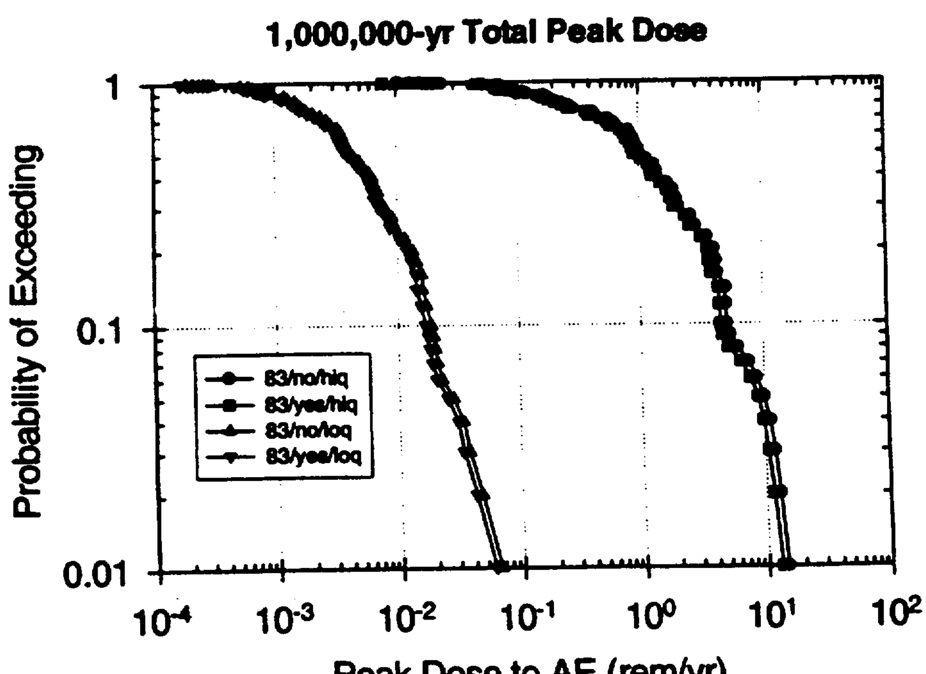


Figure 9.3-13 CCDF of Total Peak Dose: 1,000,000 years, 83 MTU/acre, with ("yes") and without ("no") backfill, high and low infiltration (q_{inf}) ranges, cyclical-q_{inf} climate model.

SUGGESTIONS FOR WASTE CONTAINMENT AND ISOLATION STRATEGY

- **Strategy is not a regulatory requirement**

- **Strategy is potentially a useful high-level tool for demonstration of program integratio ı and progress**

(1) The waste isolation strategy should have a clear relationship

to performance assessment.

- **System Flow Diagram**
- **Importance Analysis**
- **CCDF Sensitivity Plots**

(2) If the strategy is based on a multiple barrier approach, importance of repository subsystems and/or components to containment and isolation could be different than to total system performance.

- **Performance Allocation**
- **Barrier Boundary CCDFs**

(3) The strategy should provide a crosswalk between the strategy and the TSPA, process level modeling, and field and laboratory testing.

- **References to TSPA should be specific**

EXAMPLE:

HYPOTHESIS: **Capillary forces limit seepage into the emplacement drifts to a small fraction of the incident precolation flux.**

- **(7.3) $(q_{perc} - K_{sat}) = q_{drip}$; q_{perc} and q_{drip} are from sampled distributions, Drip distributions are assumed to be stationary.**

- **only flux greater than 10^{-4} mm/yr assumed to drip**

(4) Processes, parameters, assumptions, and etc. common to more than one key attribute of the system should be clearly identified.

- **Percolation flux can affect seepage, containment, mobilization, and transport.**

- **Thermal loading can affect seepage, containment, and mobilization.**

(5) The strategy should identify components (hypotheses) the importance of which could be sensitive to design or regulatory uncertainties.

- **Importance of containment could be a function of performance assessment period.**

- **Dilution is of great importance for an individual dose standard and of lesser importance for a population dose or release quantity standard.**

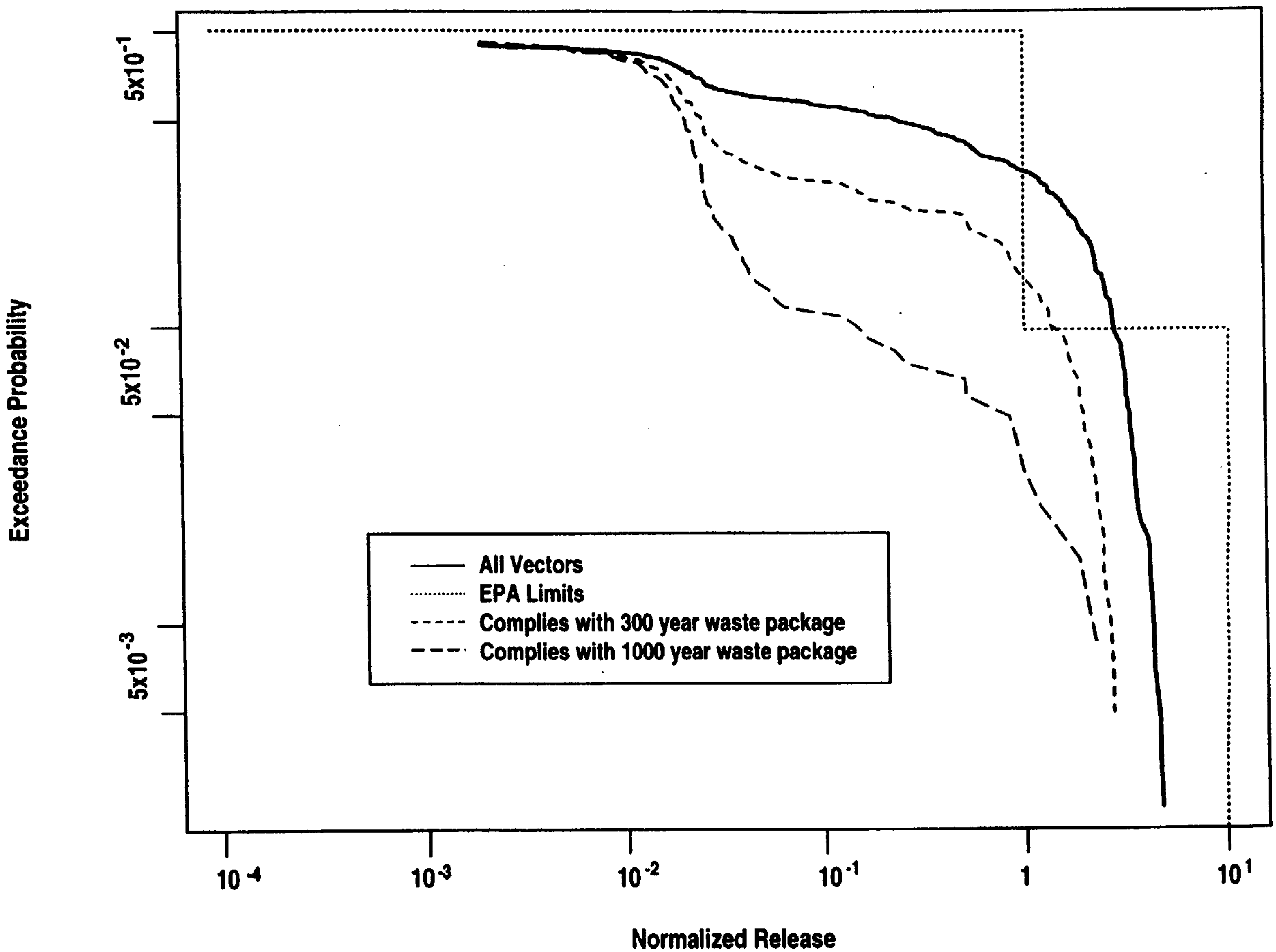


Figure 9–12c **CCDF sensitivity plot for waste package failure times for base case scenario** (gaseous release only)

BREAKOUT SESSION SUMMARY: WORKING GROUP 1

Issue	*Discussion*	*Action*
	TEMPERATURE AND RELATIVE HUMIDITY	
Conceptual models addressing heat and relative humidity (RH)	Appears at present to be a choice of "equivalent continum model" (ECM) vs. "dual porosity" or discrete fracture models	Possible topic for technical exchange, Appendix 7 visit, or telecon, as arranged.
Differences between TSPA-95 and CNWRA values for initial temperature and effective conductivity	DOE recognizes differences between TSPA-95 and TSPA-93 (Sandia) calculations. For above boiling conditions, the definition of RH used in TSPA-95 was inconsistent with literature.	DOE will re-evaluate. NRC/ CNWRA suggest using the term "vapor pressure ratio" instead of RH.
Computational problems associated with high infiltration	Currently being investigated by DOE's Management & Operating (M&O) contractor and Sandia performance assessment staffs and CNWRA	Possible topic for technical exchange, Appendix 7 visit, or telecon, as arranged: hydrothermal modeling
Waste package characteristics at repository edge (periphery)	Design issues (e.g., waste stream) yet to be resolved.	Later information exchange between NRC and M&O recommended. NRC plans to monitor design development.
	CONTAINER LIFE AND SOURCE TERM	
Process for determining importance to performance	Lawrence Livermore National Laboratory (LLNL) has ongoing studies to experimentally or logically defend container failure scenarios. DOE agrees with need for subsystem sensitivity studies.	Possible topics for technical exchange, Appendix 7 visit, or telecon, as arranged — subject: design-specific calculations of temperature and material properties

Waste package degradation: • extrapolation of data • extreme value or normal distribution for pitting • critical RH vs. temperature • impermeable vs. porous scale • pit growth vs. environment	For extrapolation of data, it is DOE's position that: • Critical processes can be determined from short term • Behavior verified by long term • LLNL (site scale – 5 years) • Literature (30 years) • Analogs (long time) Extreme value vs. Normal Distribution for pitting: DOE will evaluate paper provided by CNWRA Critical RH vs. temperature and chemistry: DOE acknowledges concern Impermeable vs. porous-scale formation: DOE acknowledges concern Pit growth as a function of environment:	LLNL will synthesize available data for extrapolation. CNWRA provided DOE with paper by Sharland *et al.* (1995) and will provide additional literature. Work in progress. Work in progress. Ongoing experiments.
Near-field environment	Recommended treating in a separate meeting that would include design engineers and site characterization investigators.	Possible topic for technical exchange, Appendix 7 visit, or telecon, as arranged: Fall 1996 time frame
Waste dissolution/near-field/Source term	Answers expected from experiments and subsystem sensitivity studies. Work is in initial phase.	None

BREAKOUT SESSION SUMMARY: WORKING GROUP 2

Issue	*Discussion*	*Action*
(SYSTEM) ABSTRACTION		
Markovian calculations	Clarification requested on where these type of calculations are described.	See RIP Manual, Version 4.0 (Golder Associates, 1995; pp. 4-16 — 4-21). NRC staff will try to relate Markovian calculations to fundamental physical parameters.
Model dependency on conclusions/assumptions	In terms of process modeling, NRC staff interested in understanding what DOE did and why.	More/additional detail would be useful in future TSPA documentation. Possible topic for technical exchange, Appendix 7 visit, or telecon, as arranged — subject: DOE's TSPA abstraction process.
Limit of response curve	TSPA using response curves to represent the performance of subsystems and ranges in parametric values. Do response curves adequately describe the processes being modeled and the coupling of processes ?	More/additional detail on what these curves mean would be useful in future TSPA documentation, including an examination of how well abstractions represent process modeling.
Importance of drift-scale calculations	Questions concerning the importance of these types of calculations (particularly as they relate to episodic phenomena) when scaled-up to the repository level. (Also see "Differences between container failure times and release times," below.)	Possible topic for technical exchange, Appendix 7 visit, or telecon, as arranged — subject: effects of episodic radionculide release phenomena on repository performance.

Correlation between units spatially and vertically. Is there any? Is the abstraction in TSPA-95 correct in its treatment ?	Additional clarification and discussion on what the issues where. Correlation of physical properties within and between units needs to be addressed. It was mutually recognized that this issue is potentially important to repository performance.	DOE will address vertical as well as horizontal correlations of physical properties within stratigraphic units.
FLOW (INFILTRATION)		
Fracture properties	Questions raised on the source(s) for the parameter values.	No consensus on which parameters are important or their ranges.
Areas of focused infiltration: Importance and derivation	TSPA does not adequately address this issue. It was mutually recognized that this issue is potentially important to repository performance.	Currently being evaluated by the USGS. Possible topic for technical exchange, Appendix 7 visit, or telecon, as arranged (e.g., flow and transport).
Climate change over 10,000 years	Discussion focussed on how the onset of pluvial conditions would be treated in a TSPA. Discussion also focussed on whether the range in parametric values selected are adequate.	Differences in the respective staff approaches needs to be addressed. Possible topic for technical exchange, Appendix 7 visit, or telecon, as arranged (e.g., flow and transport).
Are TSPA-95 fracture velocities incorrect?	What percentage of the flux is fracture flow. At this time issue is not considered to have a significant effect on performance.	It was agreed that the fracture velocities should have been adjusted for saturation but effect on performance may not be significant.
Importance of lateral flow	It may be important if it occurs; however, it is not clear at this time whether it occurs at the site.	More data is needed to resolve this issue. Possible topic for technical exchange, Appendix 7 visit, or telecon, as arranged (e.g., flow and transport).

Fracture-matrix partitioning	Discussion related to "Markovian calculations," above.	-----
	DILUTION	
Basis/rationale for mixing depth assumed in TSPA-95	Depth assumed; no information to form an estimate at this time. NRC not convinced that significant mixing takes place below the repository. This issue is potentially important to repository performance, especially in the context of understanding how much water is transported through the Amargosa Valley area.	DOE will examine basis for assumption.
Basis/rationale for average flux values used by NRC (0.1 m) vs. others (0.2 m)	Sampled parameter. See p. 7-21 and Chapter (dilution) in TSPA-95.	None.
	TSPA (SYSTEM) ABSTRACTIONS	
Differences between container failure times and release times	NRC concerned that DOE's modeling does not recognize that "episodic" flushing of the waste package, by ground water, could occur and lead to subsequent "spikes" in radionculide releases from the EBS.	NRC staff to do further investigations.
What is meant by NRC's "rule-based" method for fracture-matrix code	Clarification provided by NRC staff. See Chapter 4 ("Flow and Transport") in IPA Phase 2 report.	None.
CCDF charts: NRC results cover a broader range than do DOE's. What are the differences between the two models (approaches) that could account for the discrepancies? How are geometric differences in the curve accounted for?	At the "low release end," NRC's CCDF dominated by the fact that there are no waste package failures initially, whereas DOE would have failures and waste transport in each zone. At the "high release end," the CCDF differences could be attributed: (i) how fast pathways were treated in the respective codes; and (ii) DOE assumptions of significant matrix diffusion effects (re: Markovian calculations).	NRC will do more follow-up on in this area. DOE may have matrix diffusion data that NRC could use as it evaluates the Markovian computational algorithm.

TSPA Technical Exchange - May 22-23, 1996

SUMMARY CLOSING STATEMENT BY STEVE FRISHMAN FOR THE STATE OF NEVADA

Total system performance assessment of the Yucca Mountain site will continue to be burdened by an unacceptably high level of uncertainty as long as the DOE project lacks defensible conceptual models for site UZ and SZ hydrology and thermal behavior. While there may never be a consensus on which models appear to be most representative of the site and its behavior under both undisturbed and disturbed conditions, and thermally pulsed conditions, uncertainty can be reduced by further data collection that might help support or reject some of the alternatives that, at this time cannot be fully evaluated due to the lack of an adequate data base.

The DOE's Waste Isolation and Containment Strategy relies heavily upon an unsupported assumption regarding the validity of a site hydrologic conceptual model. Without improved certainty regarding conceptual models, the Strategy may lead to incorrect decisions regarding what further site characterization work is necessary to be completed for a Viability Assessment and License Application.

Both the DOE and NRC have expressed their belief that further work on the Yucca Mountain Project should focus primarily on those elements that are most important to waste isolation performance. TSPA, based on highly uncertain conceptual models, is being relied upon to expose those elements most important to performance, but there is little quantitative evidence demonstrating the validity of determinations regarding elements that are determined to be of lesser importance to performance. Ultimately, the burden will be on DOE to demonstrate that certain elements are, in fact, of little importance to waste isolation performance. At present some of the decisions regarding importance appear to be driven more by schedule and cost than by technical considerations. For example, until recently it was thought to be necessary to collect further data from additional boreholes to understand the large hydrologic gradient north of the site. But, the importance of this issue appears to have diminished as the available funds were reduced and a new project schedule was developed. The current plans do not include new boreholes and the suggestion is that understanding this feature is not important to waste isolation performance anaylsis.