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

NUCLEAR WASTE TECHNICAL REVIEW BOARD
FULL BOARD MEETING

SUBJECT: TSPA-1995 OBJECTIVES AND APPROACH: FOCUS ON WASTE PACKAGE/EBS CONCEPTUAL MODELS

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Outline of Presentation

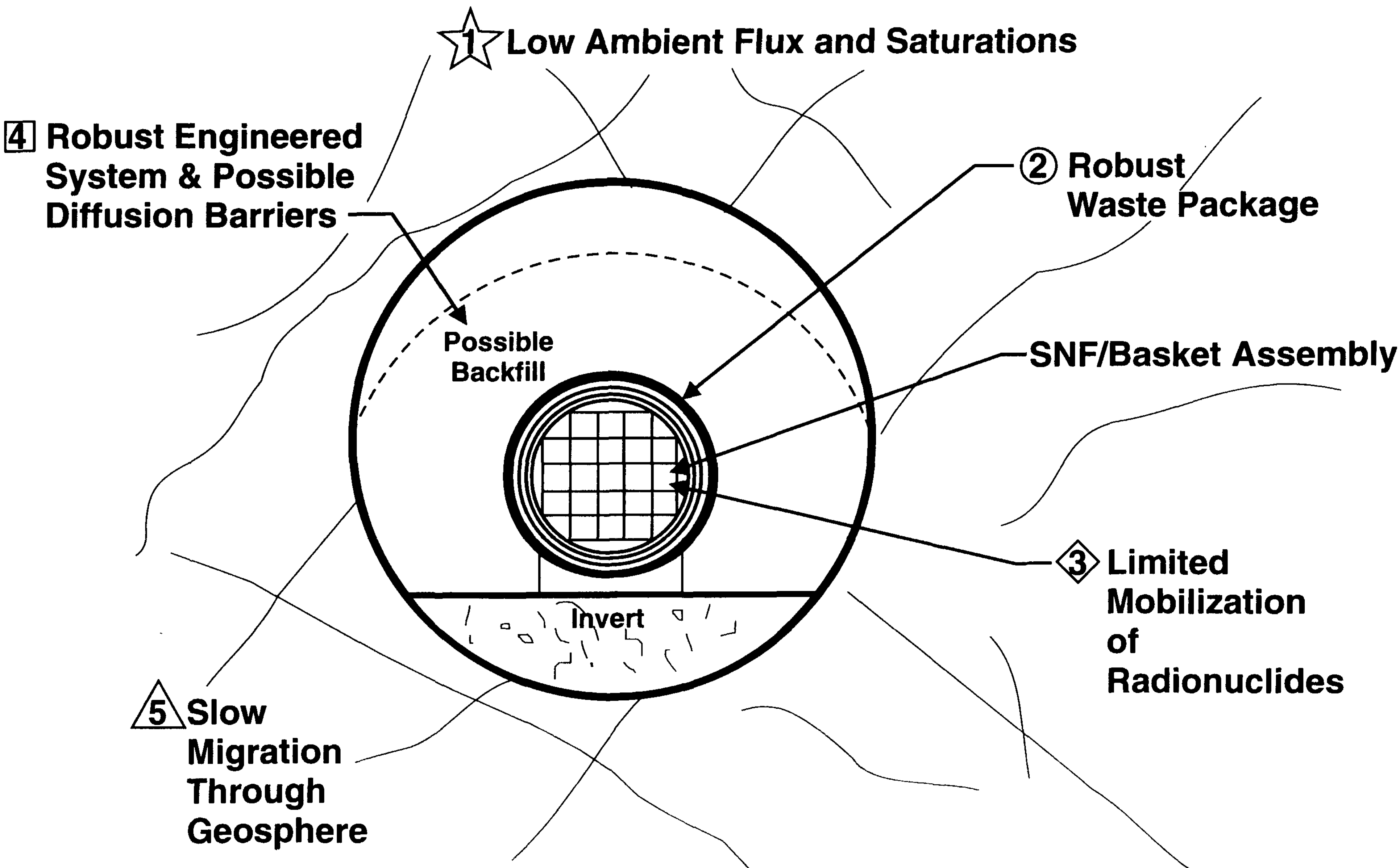
- Components of TSPA-1995
- Major waste package/engineered barrier system (EBS) conceptual and parameter uncertainties identified in TSPA-1993
- Design information since TSPA-1993
- Objectives of TSPA-1995

Outline of Presentation

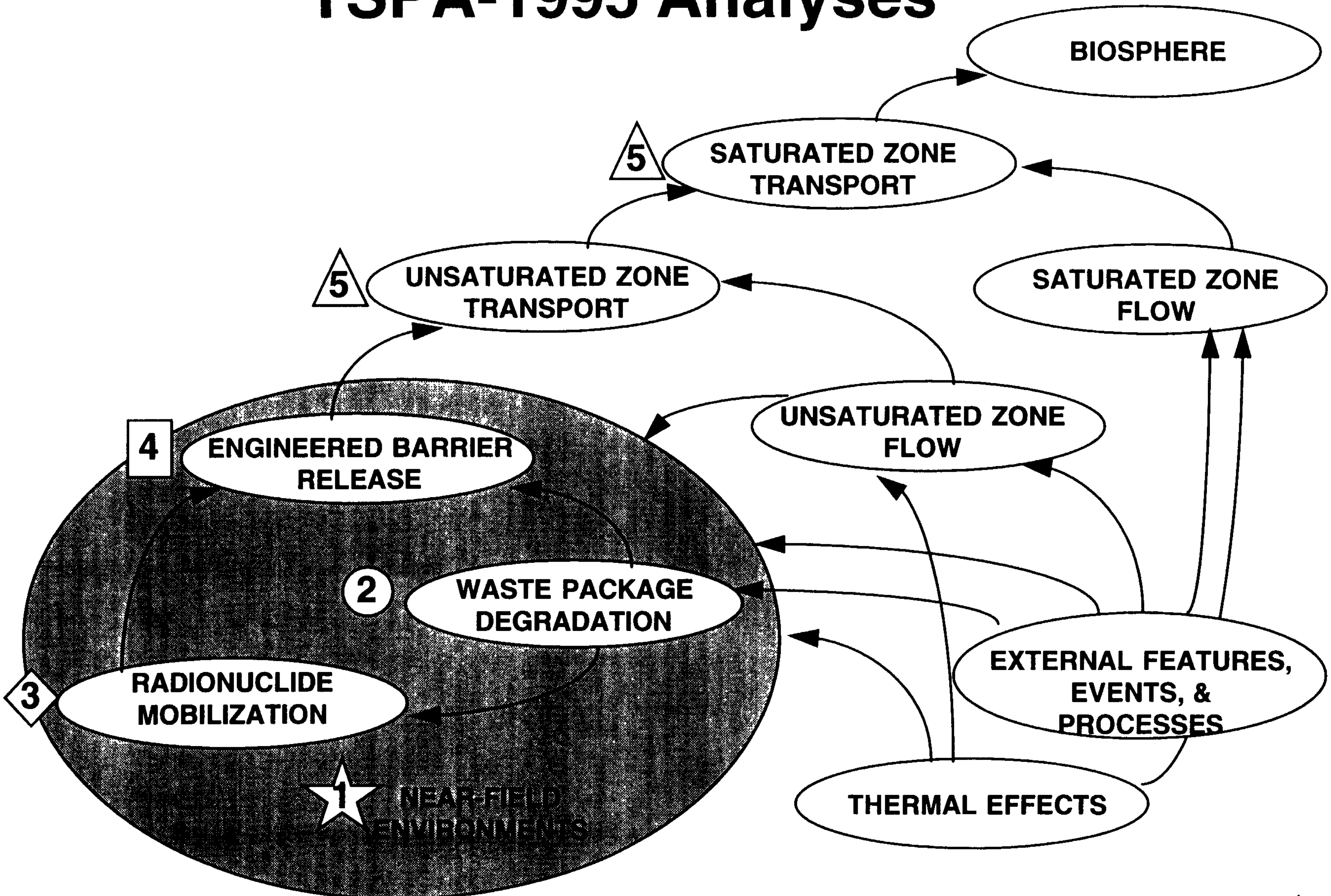
(Continued)

- Incorporation of uncertainty in waste package/EBS conceptual models used in TSPA-1995
  - Drift-scale thermal hydrology
  - Alternative backfill designs
  - Corrosion initiation and rate
  - Radionuclide mobilization
  - Waste package/EBS release
  - Colloid-enhanced radionuclide mobility and transport
- Schedule for TSPA-1995
- Summary and Conclusions

Top-Level Strategy for Waste Isolation



Important Components of TSPA-1995 Analyses



Major Waste Package/EBS Conceptual Uncertainties Identified in TSPA-1993

- Conceptual model of fracture-matrix flow
- Incorporation of in-drift thermal hydrology
- Initiation criteria for aqueous corrosion
- Waste package degradation models
  - Especially highly corrosion-resistant materials
- Cladding degradation models

[NOTE: Significance of uncertainty depends on performance measure and time]

Major Waste Package/EBS Conceptual Uncertainties Identified in TSPA-1993

(Continued)

- Definition of waste package "failure"
- Water contact with waste form
- Radionuclide solubilities (especially Np)
- Waste package/EBS release model
- Conceptual model of fracture-matrix transport

[NOTE: Significance of uncertainty depends on performance measure and time]

Design Information Since TSPA-1993

- Two areal mass loadings (AML)
  - Low (25 MTU/Acre)
  - High (83 MTU/Acre)

  [Note: Thermal load depends on AML and thermal management]
- Four conceptual waste package designs dependent on thermal load and waste type
  1. Spent fuel, low thermal load
     - » Outer: moderately corrosion-resistant material (Monel 400)
     - » Middle: corrosion-allowance material (mild steel)
     - » Inner: highly corrosion-resistant material (Alloy 825)
  2. Spent fuel, high thermal load
     - » Outer: corrosion-allowance material
     - » Inner: highly corrosion-resistant material

Design Information Since TSPA-1993

(Continued)

3. HLW, low thermal load
   - » Outer: moderately corrosion-resistant material (Monel 400)
   - » Middle: moderately corrosion-resistant material (70/30 Cu-Ni)
   - » Inner: highly corrosion-resistant material
4. HLW, high thermal load
   - » Outer: moderately corrosion-resistant material (70/30 Cu-Ni)
   - » Inner: highly corrosion-resistant material

   [Note: Alternative designs being considered]

- Two primary backfill options (yes or no)
- Two primary ventilation options (yes or no)

General Objectives of TSPA-1995

- Incorporate more representative results (and uncertainty) from process models into abstracted TSPA models
- Test significance of conservative assumptions
- Evaluate sensitivity of conceptual uncertainty
- Evaluate range of alternative performance measures
  - Mean time to waste package "failure"
  - Peak EBS release rate
  - 10^4 and 10^5 yr cumulative release at accessible environment
  - 10^4, 10^5, and 10^6 yr peak individual dose at accessible environment

Detailed Objectives of TSPA-1995

- Incorporate more representative treatment of drift -scale thermal hydrology and uncertainty
- Analyze two thermal loads and two backfill options (total four design options)
- Utilize more reasonable estimates of waste package degradation pitting-corrosion models and rates and their uncertainty
- Evaluate impact of cladding performance on EBS release

Detailed Objectives of TSPA-1995
(Continued)

- Incorporate uncertainty in percent of waste packages degraded over time
- Incorporate uncertainty in waste form dissolution rate and radionuclide solubility functional relationships
- Evaluate alternative definitions of 7,000 MTU of HLW
- Incorporate enhanced radionuclide mobility due to pressence of natural colloids
- Define the correlation between alternative measures of post-closure performance

Incorporation of Drift-Scale Thermal Hydrology Uncertainty

Incorporation of Drift-Scale Thermal Hydrology Uncertainty

- Consider four design options
  - 25 and 83 MTU/Acre
  - With and without backfill material
    - » Backfill, if used, emplaced at 100 years
- Consider 21 PWR waste package placed on invert material
- Consider ranges in parameters (assumed uncertain and/or variable)
  - Percolation flux
  - Hydrologic properties of TSw2
  - Normal vs. enhanced vapor diffusion

Incorporation of Drift-Scale Thermal Hydrology Uncertainty

(Continued)

- Conduct multiple deterministic analyses of drift-scale thermal hydrology for each design option to determine transient
  - Humidity at waste package surface
  - Temperature at waste package surface
  - Water content in drift materials
  - Aqueous flux through drift materials
- Use humidity (fn(t)) to determine humid air and aqueous corrosion initiation
- Use temperature (fn(t)) to define temperature-dependent properties
- Use water content (fn(t)) to define effective diffusion coefficient
- Use aqueous flux (fn(t)) to define advective release

Evaluation of Potential Effects of Alternative Backfill Designs

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- Possible effects of emplacing backfill on drift-scale thermal hydrology
  - Temperature higher for longer times
  - Humidity lower for longer times
  - Invert, packing, and backfill liquid saturations lower for longer times
  - May divert advective flux, if properly engineered
- All of above effects will be considered in TSPA-1995
  - Diversion of advective flux studied as sensitivity case

Evaluation of Potential Effects of Alternative Backfill Designs

(Continued)

- Possible consequences of modified drift-scale thermal hydrology on performance
  - Lower humidities tend to delay initiation of humid air and aqueous corrosion
  - Lower humidities tend to decrease humid air corrosion rates
  - Increased temperatures tend to increase humid air corrosion rates
  - Aqueous corrosion rates tend to be greatest at about 60° C (lower rates at $T < 60°$ C and $T > 60°$ C)
  - Increased temperatures tend to increase pitting-corrosion rates of highly corrosion-resistant material
  - Lower water contents tend to decrease area of waste form in contact with water
  - Lower water contents significantly decrease effective diffusion coefficient in EBS

Evaluation of Potential Effects of Alternative Backfill Designs
(Continued)

- All of these potential consequences will be included in TSPA-1995
- Competing effects makes *a priori* prediction of consequence difficult

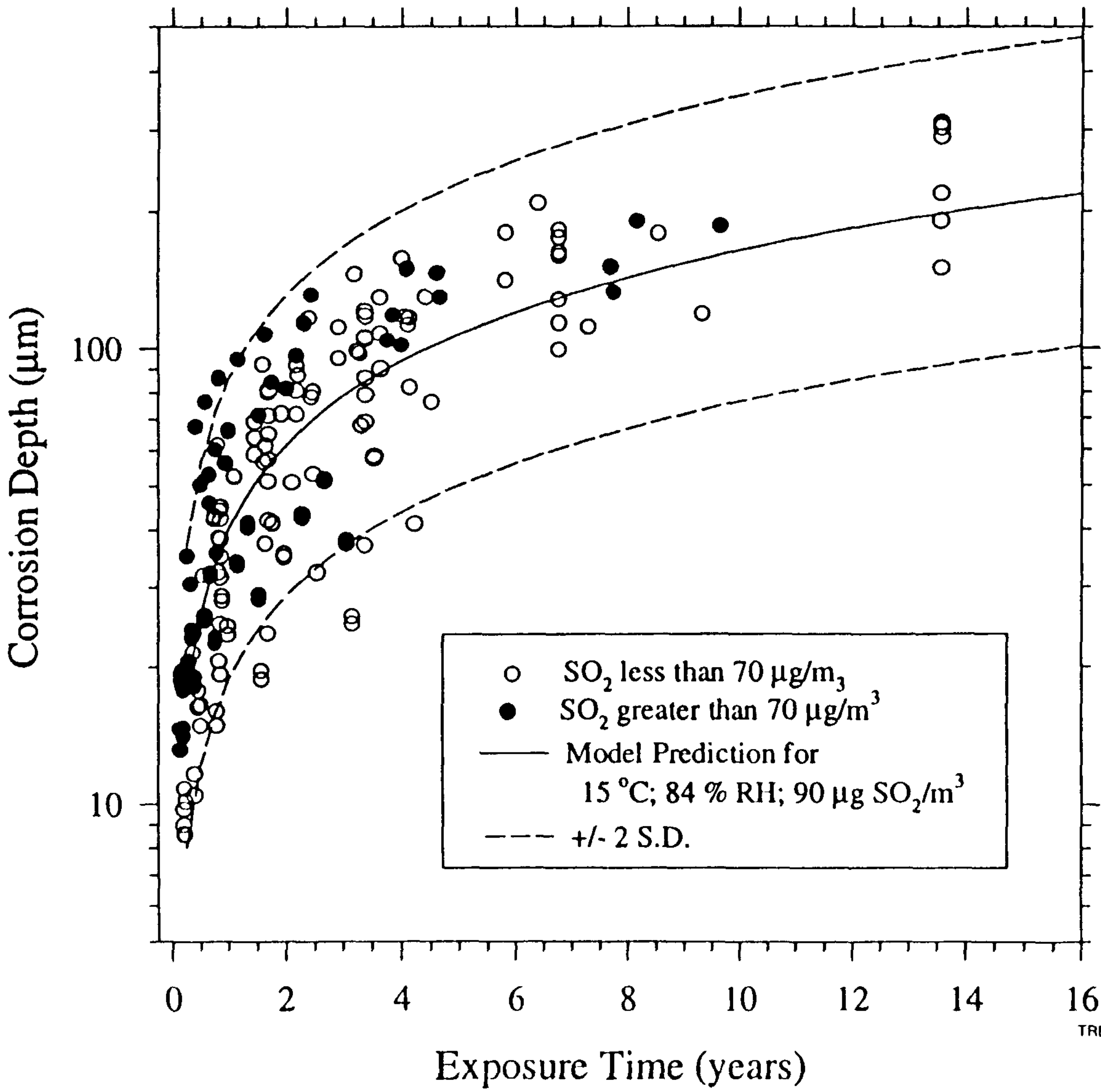
Incorporation of Corrosion Initiation and Rate Uncertainty

Incorporation of Corrosion Initiation and Rate Uncertainty

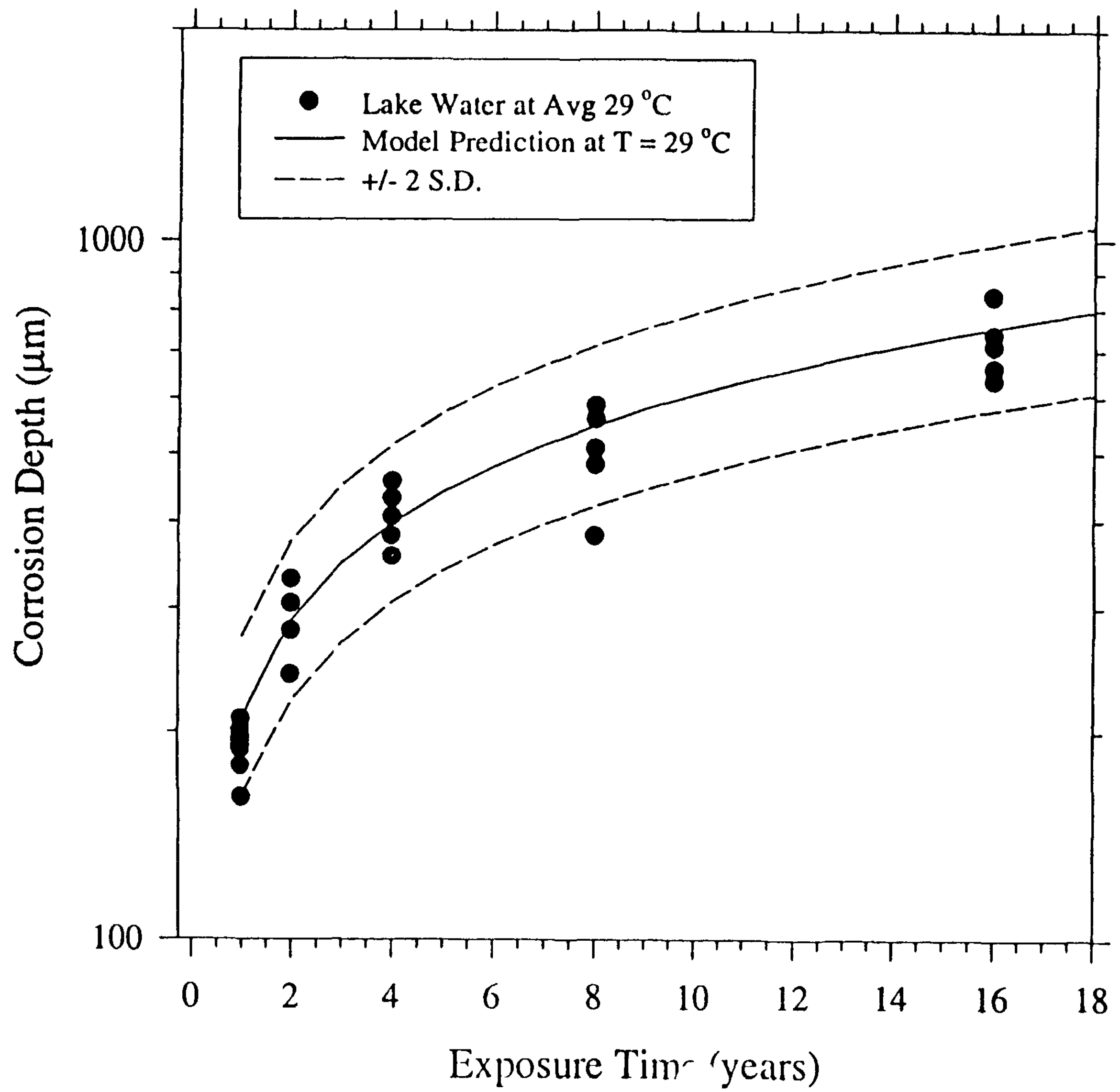
[For each thermal load and backfill option]

- Initiation of humid air corrosion starts at relative humidity of 70% (vary from 60 to 80%)
- Initiation of aqueous corrosion starts at relative humidity of 95% (vary from 90 to 100%)
- Uniform corrosion rate of corrosion-allowance material varies with humidity, temperature, and time
  - 16 years of data; 166 data points
  - Data from range of tropical and urban test locations
  - Tropical data from Naval Research Laboratory in Panama
  - Marine locations not included
  - Limited temperature range (to 27° C)
  - Data normalized to define time relative humidity > 70%

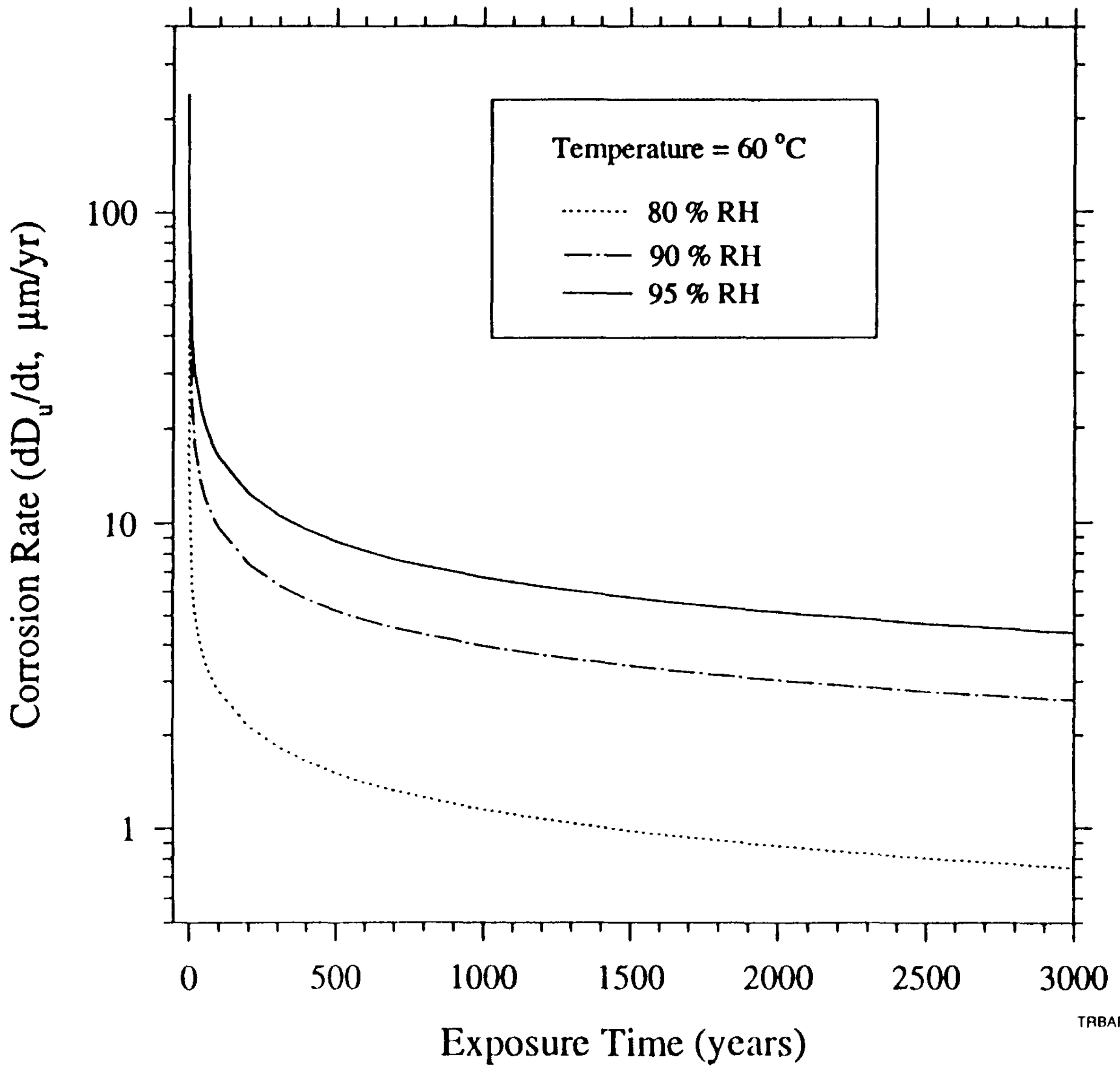
Uniform Corrosion of Corrosion-Allowance Materials (in Humid Air Environment)



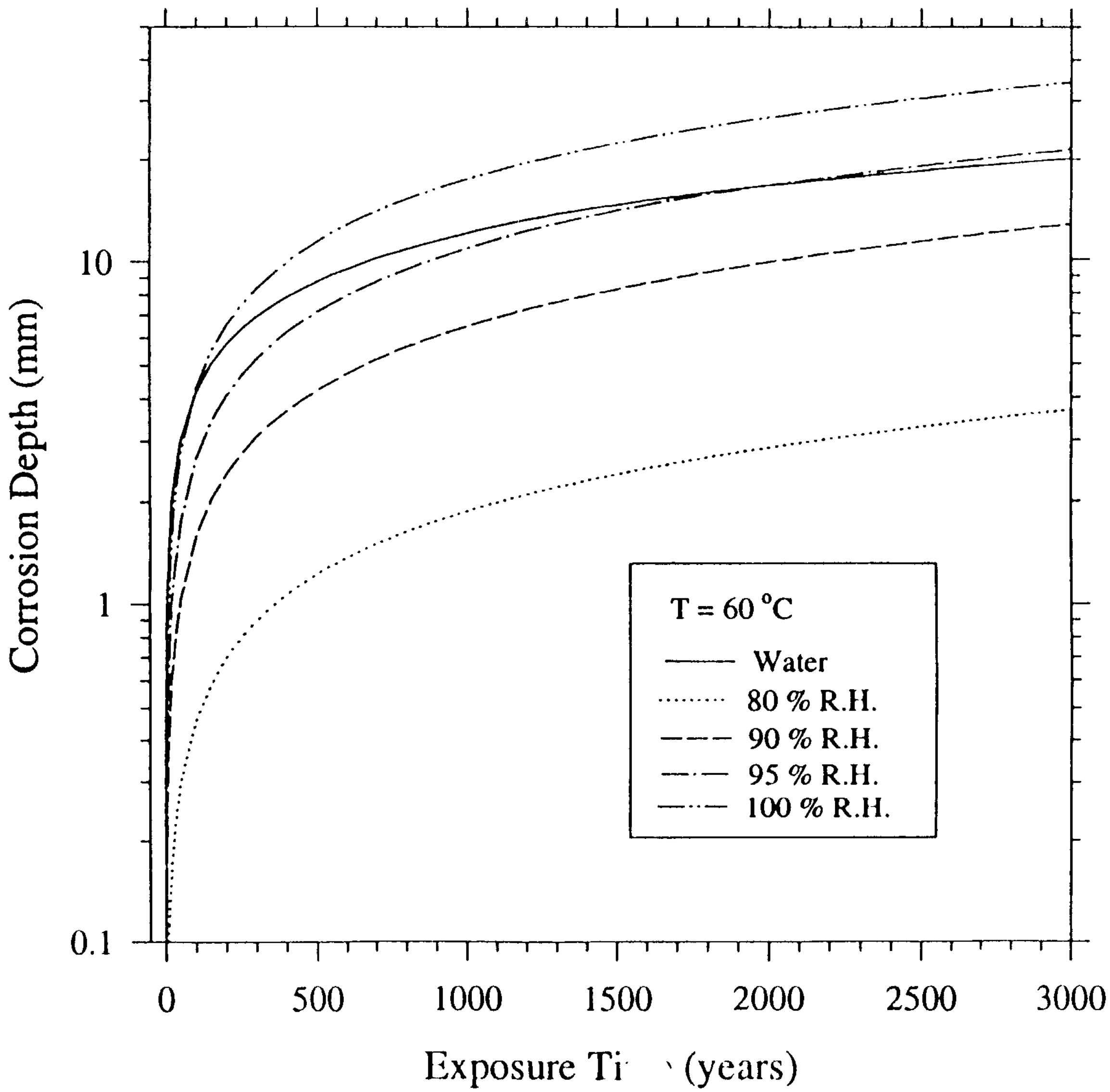
Uniform Corrosion of Corrosion-Allowance Materials (in Natural Water)



Uniform Corrosion Rate of Corrosion-Allowance Material in Humid Air



Comparison of Uniform Corrosion of Corrosion-Allowance Material (Corrosion in Water vs Humid Air)



Incorporation of Corrosion Initiation and Rate Uncertainty

(Continued)

- Localized corrosion rate of corrosion-allowance material is about 4 times the uniform corrosion rate (vary from 2 to 6 times)
  - Data from Naval Research Laboratory
- Pitting corrosion of highly corrosion-resistant material is a function of temperature and uncertain/variable
  - Log-normally distributed with a factor of 100 difference between 5th and 95th percentile (based on Lamont, 1993)
- Pitting corrosion of moderately corrosion-resistant material is about 5 times rate of highly corrosion-resistant material (vary from 2 to 10 times ?)

Incorporation of Corrosion Initiation and Rate Uncertainty

(Continued)

- Cathodic protection of highly corrosion-resistant material conservatively not included
  - May be evaluated in sensitivity analysis
- Galvanic coupling of corrosion-allowance material beneath moderately corrosion-resistant material increases pitting of corrosion-allowance material by 2 to 6 times
- Uncertainty/variability in pit growth assumed to be equally distributed from package to package and from pit to pit

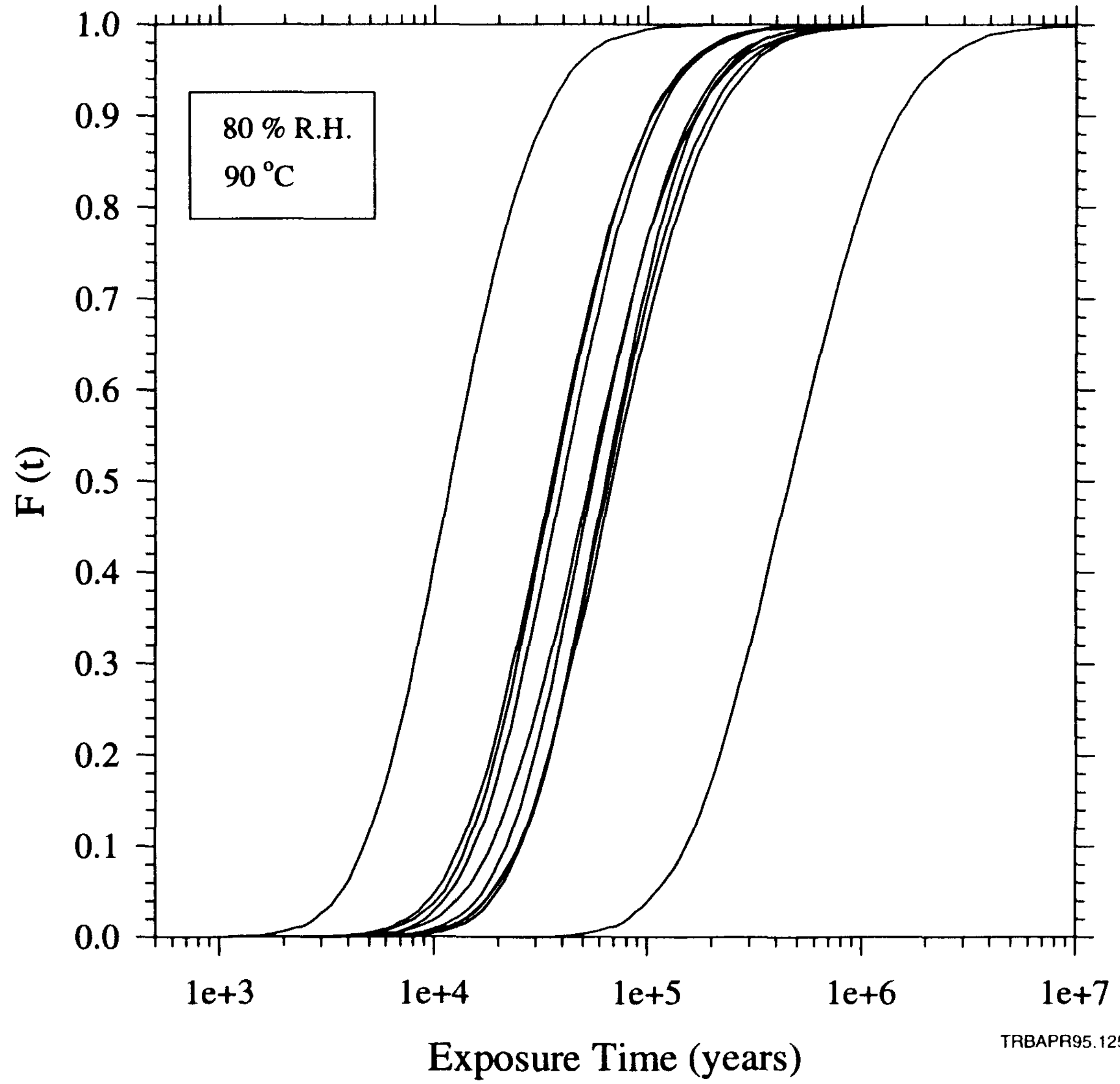
Incorporation of Corrosion Initiation and Rate Uncertainty

(Continued)

- Calculate stochastic pit growth rate (assume no correlation of pit growth between different waste package material layers)
- Calculate distribution of pits penetrating waste package (uncertainty/variability due to uncertainty/variability in initiation and growth parameters)
- Initial pit penetration used to define "failure" distribution
- Cumulative pit distribution used to define area available for advective/diffusive release through package (assume nominal pit size of 1 mm^2)

Representative Fraction of Pits Penetrating 10 cm of Mild Steel due to Localized Corrosion for Ten Waste Packages:Relative Humidity = 80%

(variability equally split from package to package and from pit to pit)

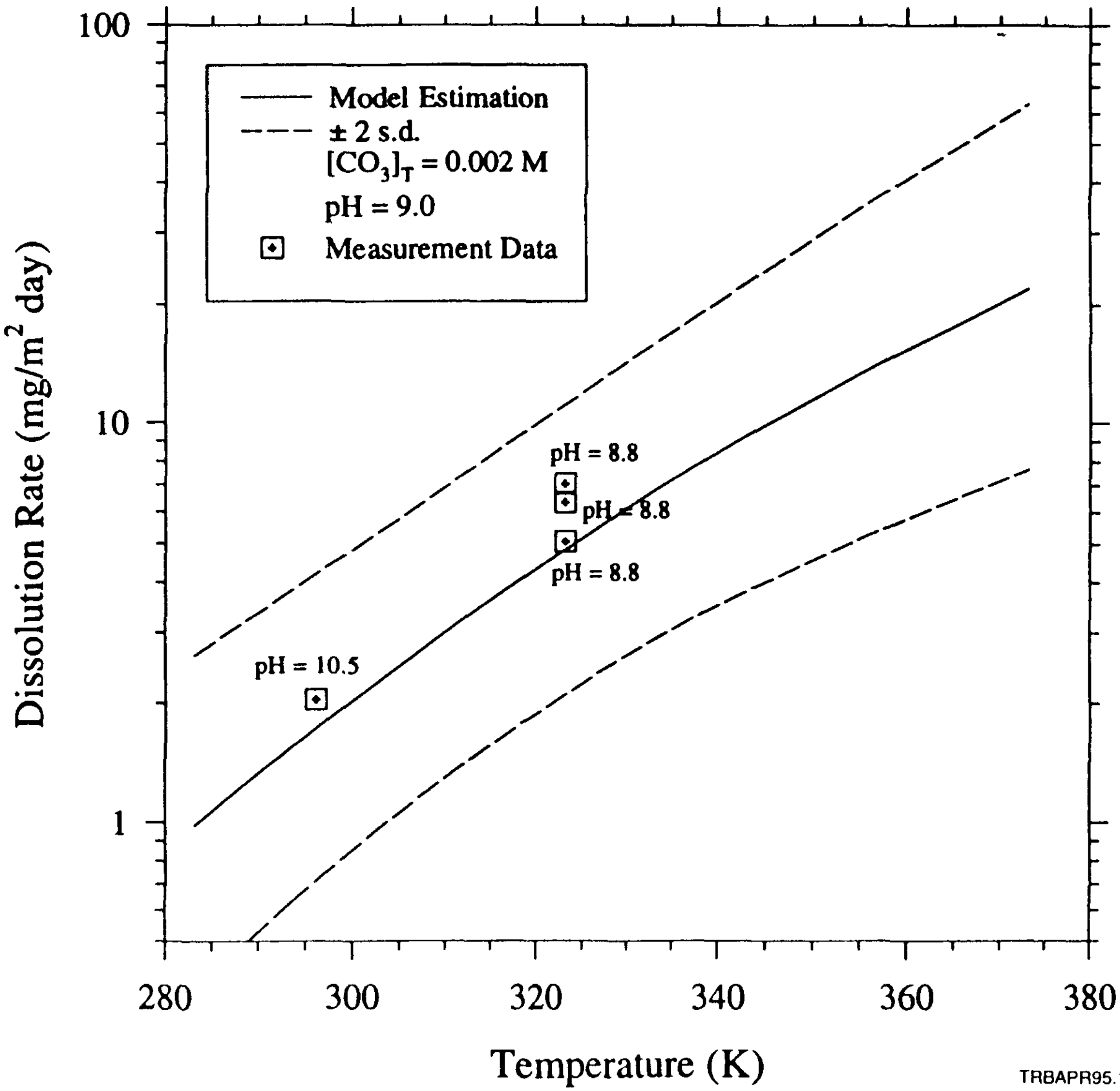


Incorporation of Radionuclide Mobilization Uncertainty

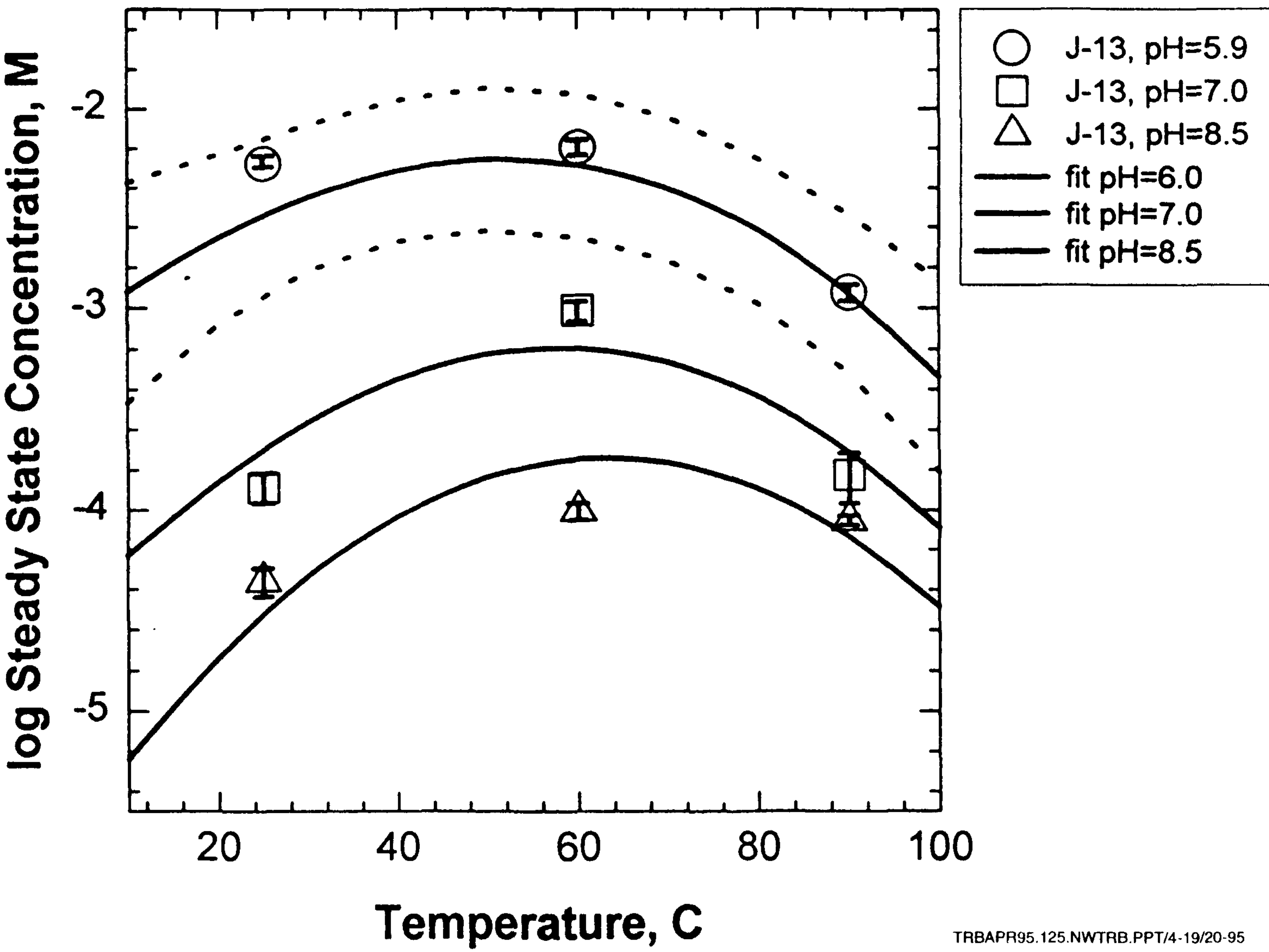
Incorporation of Radionuclide Mobilization Uncertainty

- Waste form surface exposed based on cladding degradation
  - Or, conservatively assume entire surface exposed
- Waste form surface in contact with water based on waste form surface exposed and water content
- Functional relationship of dissolution rates and uncertainty
- Functional relationship of radionuclide solubilities and uncertainty

Observed (after Gray et al.) and Model Fit Spent Fuel Dissolution Rates



Observed (after Nitsche et al.) and Model Fit Neptunium Solubilities



Incorporation of Waste Package and EBS Release Uncertainty

Incorporation of Waste Package Release Uncertainty

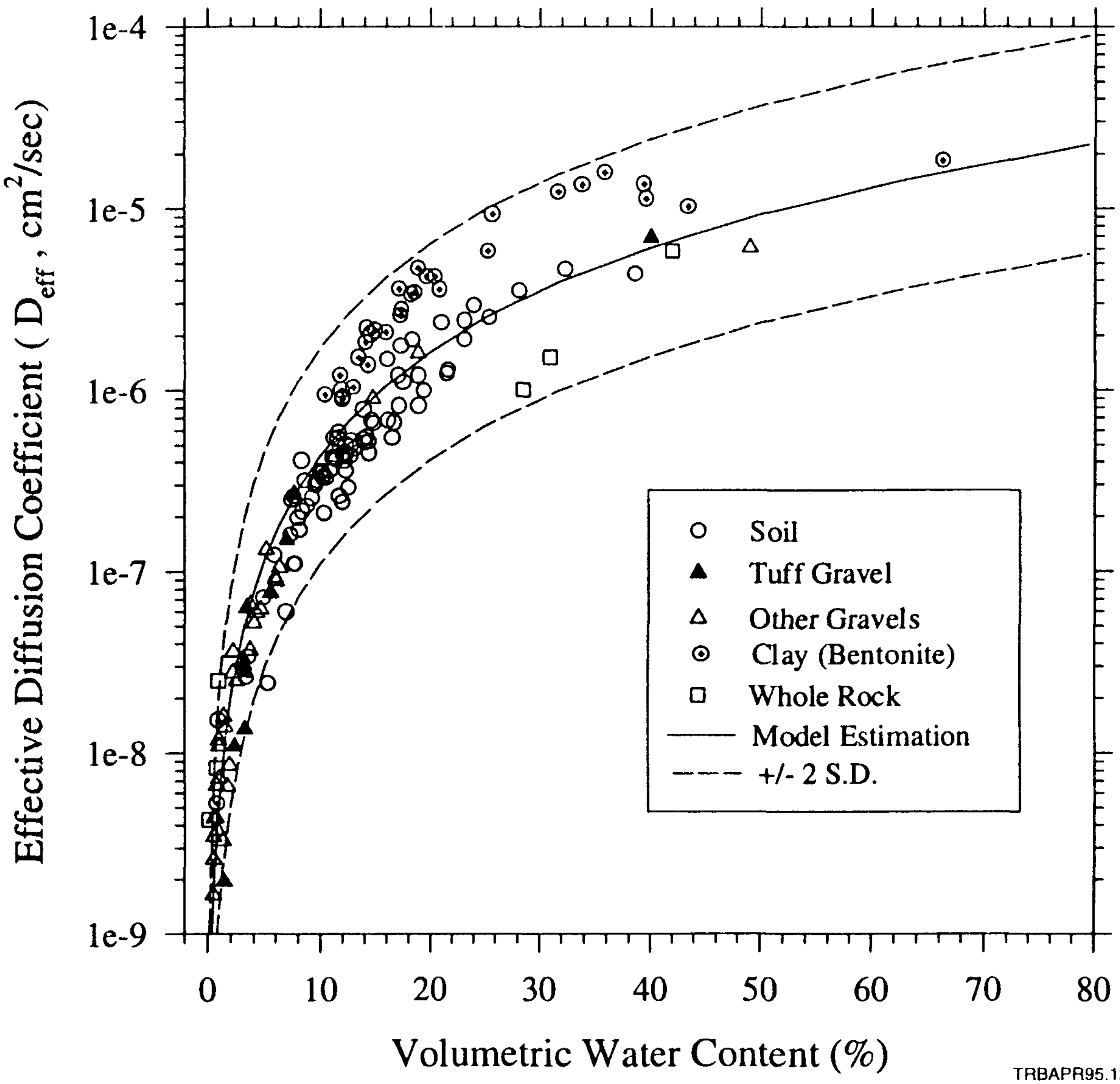
- Surface area of waste package available for advective and/or diffusive release varies with time based on pit penetration results
- Conservatively assume pits are distributed along advective/diffusive transport paths
- Advective release through package, if

  $q_{fracture\ TSw2} > 0$
- Diffusive release through package based on water content calculated from drift-scale thermo-hydrologic analyses and Conca relationship with uncertainty

Incorporation of EBS Release Uncertainty

- Assume one-dimensional transport through invert material to host rock
- Advective release through EBS, if $q_{fracture\ TSw2} > 0$, or if using flux calculated in drift-scale thermo-hydrologic analyses
- Advective velocity determined from Darcy flux, porosity, and saturation from drift-scale thermo-hydrologic analyses
- Diffusive release through EBS based on water content in invert material calculated from drift-scale thermo-hydrologic analyses and Conca relationship with uncertainty

Observed (after Conca) and Model Fit to Effective Diffusion Coefficients



Incorporation of Colloid-Enhanced Radionuclide Mobility and Transport Uncertainty

Incorporation of Colloid-Enhanced Radionuclide Mobility and Transport Uncertainty

- Ambient colloid population based on observations from J-13 water (Triay et al., 1995)
- Pu and Am irreversibly sorb onto colloids with mean measured k_D (Triay et al., 1994)
- Mobile Pu and Am is sum of aqueous solubility-limited concentration and mobile mass sorbed to colloids
- Colloidal mass of parent Pu and Am transported seperately from aqueous component
- Alternative models of filtration and sorption in Unsaturated zone fracture transport

Schedule for TSPA-1995

- Complete process-level models and model abstraction (5/95)
- Complete draft documentation (9/95)
- Present results to NWTRB (10/95)
- Present results to NRC (?12/95)
- Submit document to external review (1/96)

Summary and Conclusions

- TSPA-1995 enhancements/refinements
  - Will add to the realism/representativeness of the analyses
  - Will test the significance of the conservatisms included in earlier TSPA iterations
  - Will evaluate the importance of different components of the waste isolation and containment strategy in meeting system and subsystem performance objectives
- Conceptual underpinning of some detailed process models is still uncertain, for example:
  - Drift-scale thermo-hydrologic models
  - Pitting-corrosion degradation models for highly and moderately corrosion-resistant materials
  - Cladding degradation models
  - Waste package scale thermo-chemical models (solubility)
  - Drift-scale transport models

Summary and Conclusions
(Continued)

- However, TSPA analyses can be used to evaluate the significance of the different models and parameters
- These models (along with the unsaturated zone hydrology model) will continue to be identified by performance assessment as being of the highest priority, unless their significance is determined to be inconsequential