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

NUCLEAR WASTE TECHNICAL REVIEW BOARD
FULL BOARD MEETING

SUBJECT: INTEGRATED REPORT ON SNL AND M&O TOTAL SYSTEM PERFORMANCE ASSESSMENTS: FOCUS ON WHAT WAS LEARNED

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Outline

- Use of two approaches (SNL & M&O)
- Thermal loading
- Mode of emplacement and design alternatives
- General compliance
- Dose versus Complementary Cumulative Distribution Function (CCDF)
  - Technical challenges of dose calculations
  - Are insights different?
- Performance period

Use of Two Approaches:

Sandia National Laboratories (SNL) & Management & Operating Contractor (M&O)

Benefit of Dual Effort

- **Total System Performance Assessments (TSPAs) are complex undertakings**
  - **Opportunities for the analyst to influence the outcome**
  - **Analysts must make simplifying (abstracting) assumptions**
  - **Abstractions should reflect correct understanding of the physical system and reasonable data interpretation**

Benefit of Dual Effort

(Continued)

- International Transport Code Intercomparison (INTRACOIN) exercise lessons:
  - Codes embodying the same conceptual model, but using different numerical techniques may yield comparable results for the same person
  - But they generally do not yield comparable results because of analysts' need to interpret the physical system; (both its initial and its boundary conditions)
  - Data sets generally do not allow unambiguous specification of these judgment-based model inputs
  - The analysts' experience and understanding is vital to the credibility of the analytical results

TSPA-91: Also a Dual Effort

- TSPA-91 was a dual effort (Sandia National Laboratories and the Pacific Northwest Laboratory [PNL])
  - Two different calculational capabilities were used
  - Output results were comparable, where the range of input parameters and major assumptions were comparable
  - Built confidence in the analyses, in the results, and in the tools used

Example of TSPA-91 Benefit from Dual Modeling: Basaltic Volcanism Modeling

- SNL used a simplified basaltic volcanism model to evaluate releases

- PNL used a more mechanistic model

- Published estimates for recurrence rates and the mechanics of intrusion were used
  - SNL scenarios were based on the work done for the Yucca Mountain Project
  - PNL scenarios were based on the more general regional volcanism literature

- Results: insignificant releases

Dual Participation in TSPA-93: Building Credibility and Confidence

First Step: M&O (new team) benchmarking its capability by performing a set of comparative calculations using the RIP code with the TSPA-91 data set

- This exercise showed the SNL data set, as published, was sufficient to recreate TSPA-91 results
- Also showed the RIP code, in the hands of capable analysts
  - Could be used to perform TSPAs
  - Is flexible
  - Can be used for sensitivity studies
- Work began early-1993; results published mid-1993

Dual Participation in TSPA-93: Building Credibility and Confidence

(Continued)

Second Step: Ensure that needless differences in the two analyses would be avoided

- To the extent practical, the M&O would use results of the extensive SNL data-gathering
- The structure of the RIP code, as compared with TSA, dictated differences in use and encoding of some data
- The structure of the RIP code, as compared with TSA, also dictated differences in analytical approach

Dual Participation in TSPA-93: Building Credibility and Confidence

(Continued)

- TSPA-93, however, was not a re-benchmark of RIP and TSA:
  - Purposeful differences in approach retained to assure additional insight into the TSPA problem
  - Purposeful differences in cases run retained to ensure additional insight into the problems being addressed

Common and Contrasting Approaches in TSA and RIP for TSPA-93

- Often, the two codes used the same conceptual approach, but implementation differed in details

- Common data, approaches, and implementation contrasts are described in an appendix for
  - The approach to the one-dimensional approximation of unsaturated flow and transport
  - The composite-porosity conceptual model
  - Infiltration/flux distributions and climate change
  - Saturated zone flow and transport
  - Radionuclide solubilities and distribution coefficients
  - Waste package corrosion and near-field characteristics

Meaning of SNL and M&O Modeling Differences

- For the closest comparable cases (see following two viewgraphs) there were no differences in results that would have been meaningful from a compliance-calculation perspective

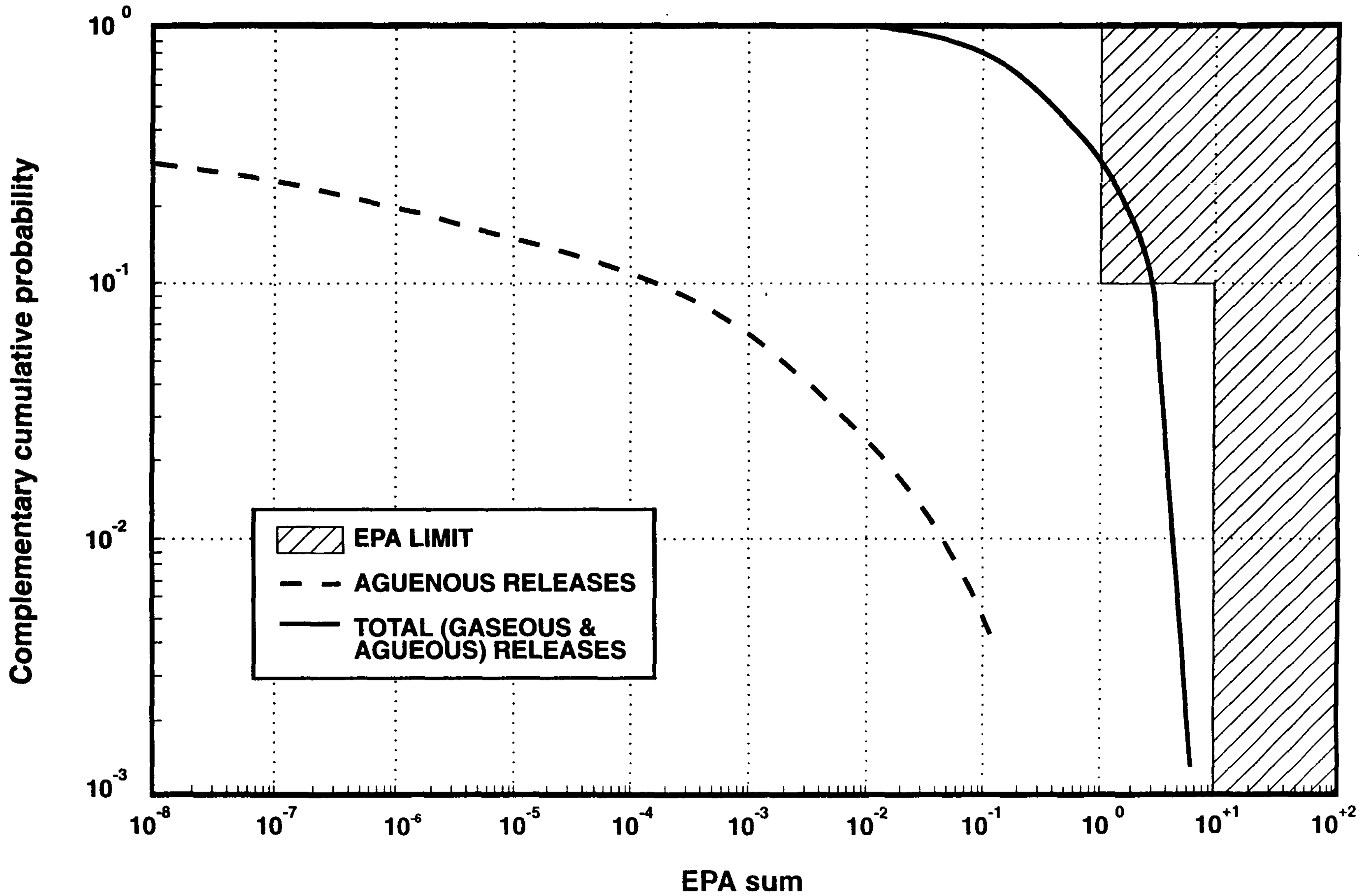
- Given these generally comparable results, it seems prudent that the performance assessment program now directs resources to

  - Evaluate the appropriateness of the conceptual model of unsaturated flow in view of alternatives

  - Link its modeling more directly to the results coming from the site program, especially its 3-D site-modeling effort

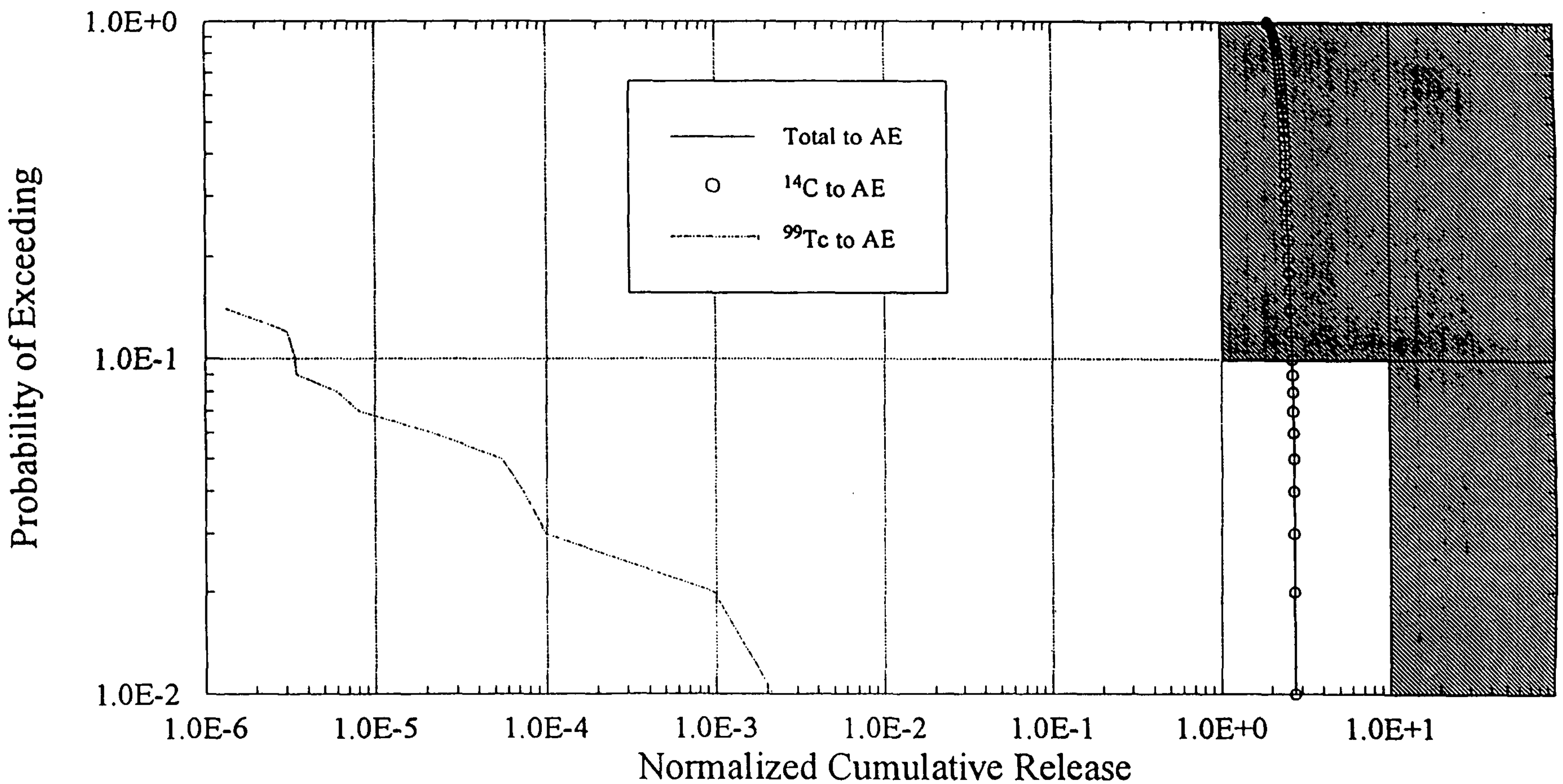
Schematic of SNL CCDFs of Normalized Cumulative Release over 10,000 Years for Nominal Aqueous and Total Releases

(57 kW/Ac; vertical emplacement, composite porosity model)



M&O CCDFs for Normalized Cumulative Releases over 10,000 years for Nominal Aqueous and Gaseous Releases

(57kW/acre, 10 cm outer and 0.95 cm inner containers, horizontal emplacement, composite porosity approximation)



Thermal Loading

Thermal Loadings Evaluated

- **M&O analyses were conducted to represent three thermal loads**
  - 70.4 kW/ha (28.5 kW/acre)
  - 141 kW/ha (57 kW/acre)
  - 282 kW/ha (114 kW/acre)

- **SNL analyses evaluated**
  - 141 kW/ha (57 kW/acre)
  - 282 kW/ha (114 kW/acre)

Alternative Designs Investigated in TSPA-93

Vertical emplacement SCP design

alloy 825 @ 0.95 cm

In-drift emplacement MPC

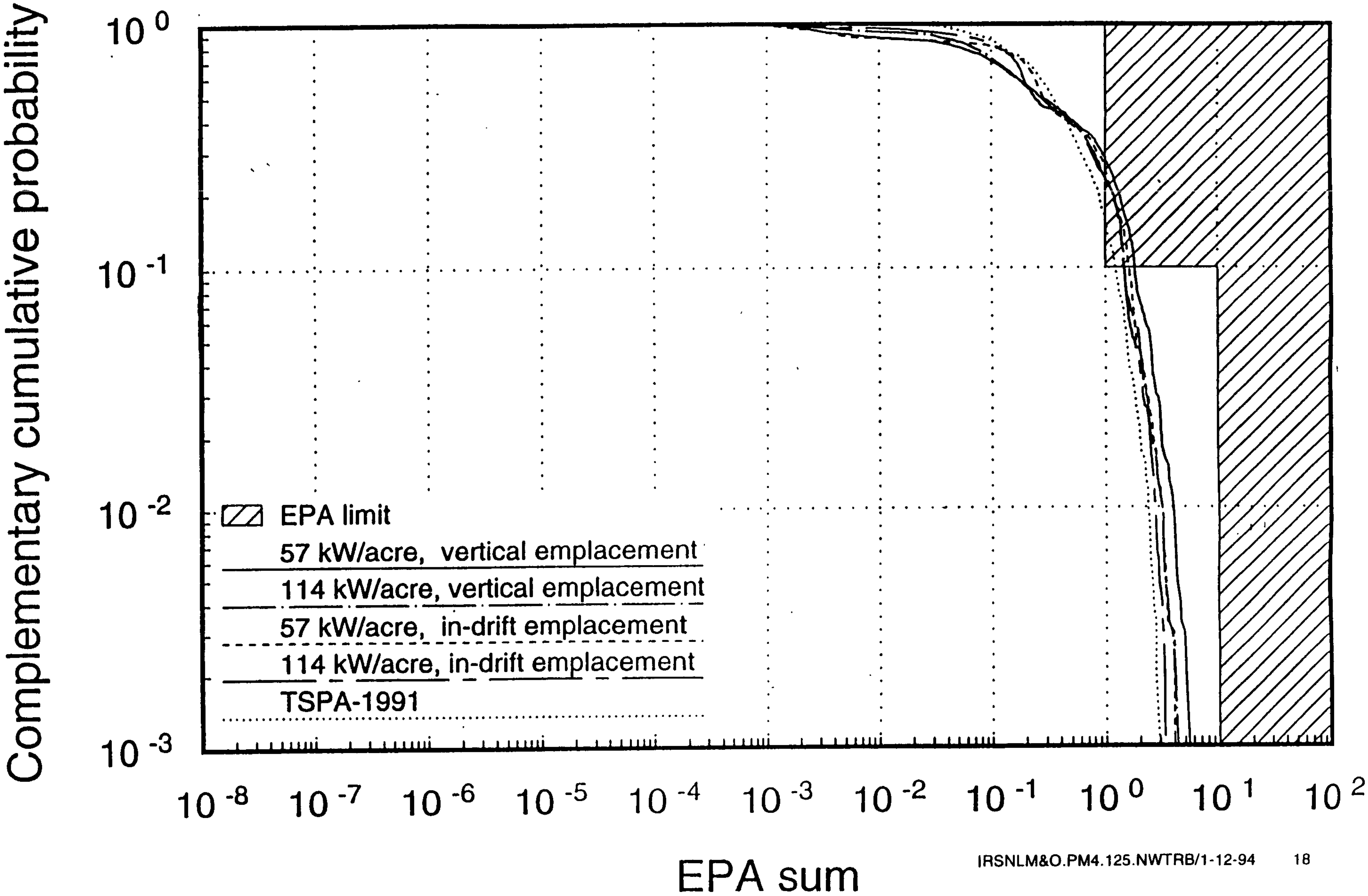
mild carbon steel @ 10, 20, or 45 cm
alloy 825 @ 0.95 cm and 3.5 cm

Design	Alternative Thermal Loads (kW/Ac)		
	28	57	114
Vertical emplacement SCP design		✓	✓
In-drift emplacement MPC	✓	✓	✓

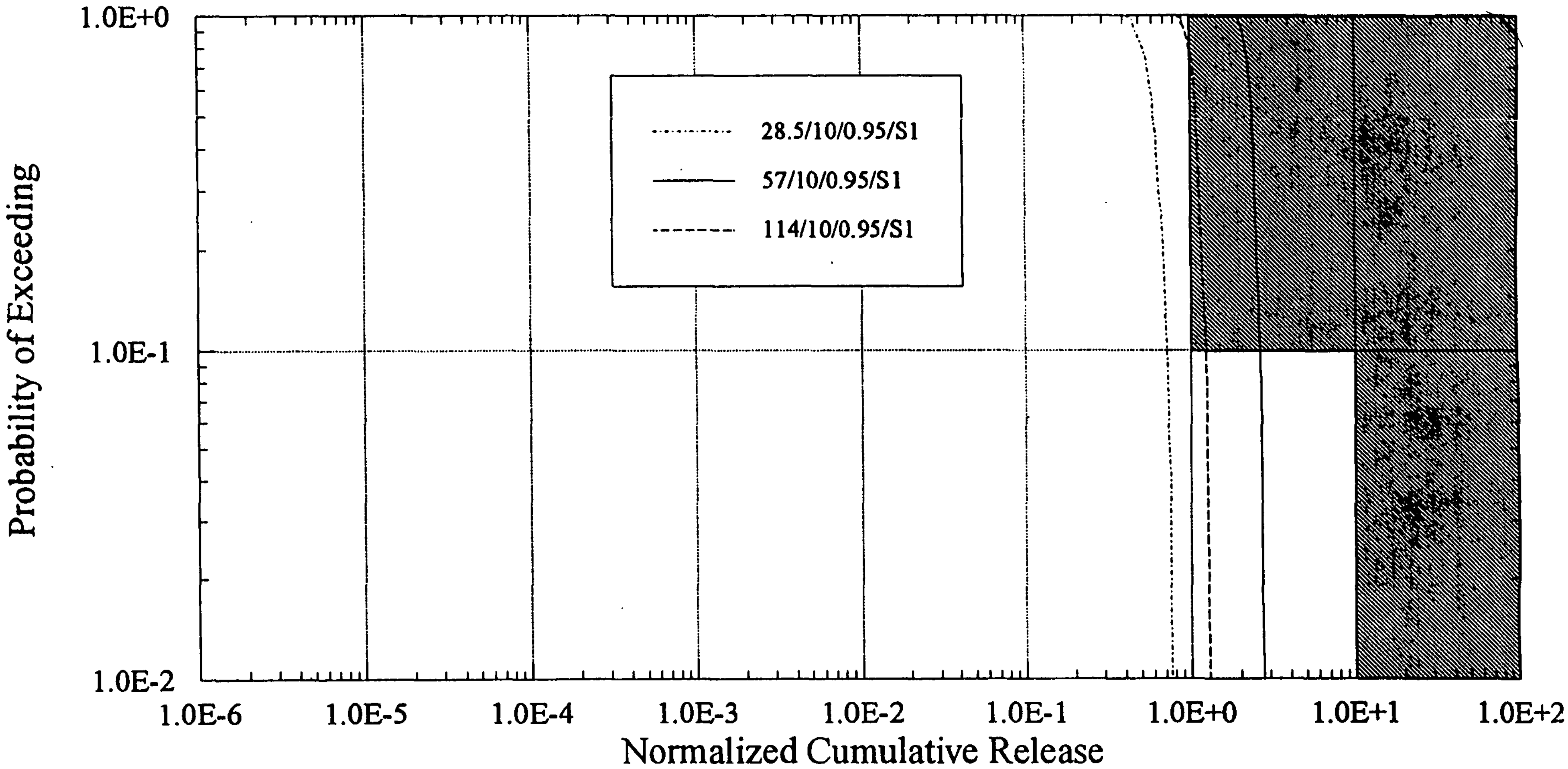
Thermal Loading Results

- There was little difference between the 57 kW/acre and 114 kW/acre cases for the 10,000-year CCDFs in the SNL analyses
- In the M&O analyses, the 28 kW/acre case seemed to give the best performance result, followed closely by the 114 kW/acre case
- The apparent differences in performance attributable to thermal loadings directly reflect how much time waste packages spend in the temperature range of 80-100°C, the temperature range, where corrosion rates are highest
- Corrosion models used were based on a limited experimental record and expert judgement: work is needed to provide more definitive corrosion models for engineered system materials

CCDFs of Nominal Cumulative Release (Aqueous and Gaseous) Over 10,000 years for the Four Cases and for TSPA-91



Thermal Loading--100 Realization at 10,000 Years: CCDF of Releases to the AE at 10,000 Years



Mode of Emplacement and Design Alternatives

Cutaway of a Drift Showing Comingled Waste Package

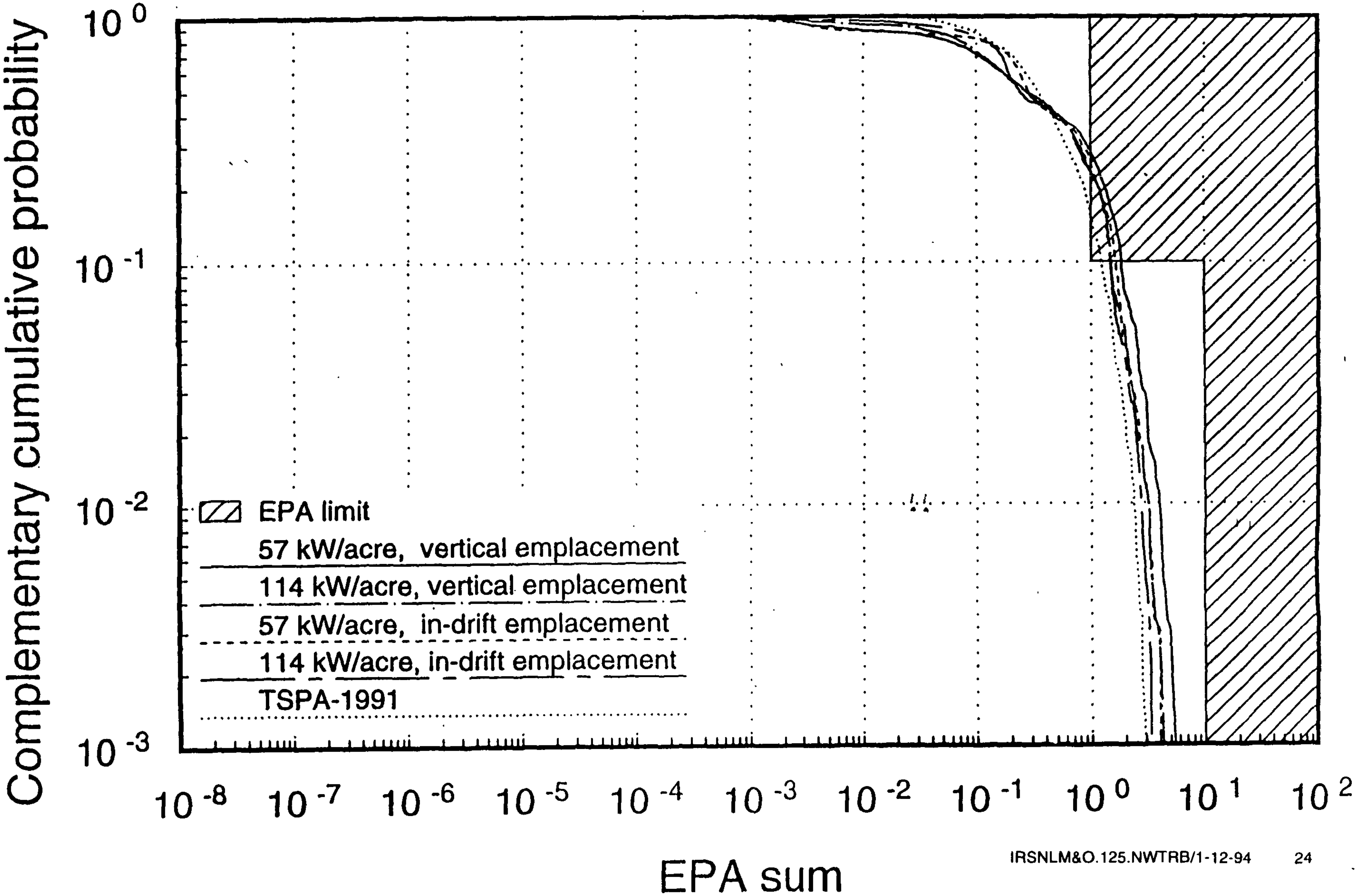
Cutaway of a Drift Showing Comingled Waste Package

Emplacement Mode

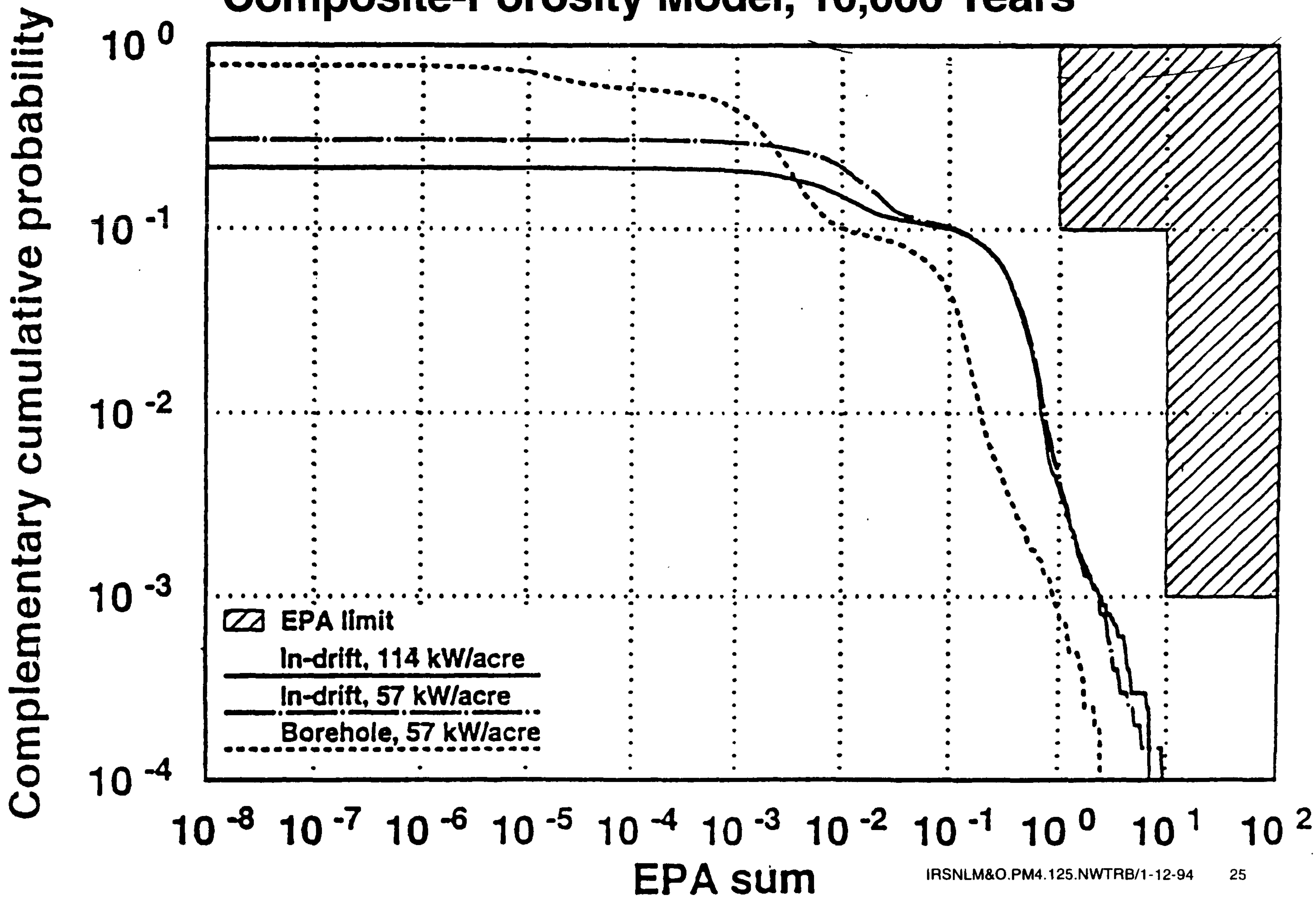
- Only SNL evaluated emplacement mode, results were non-significant differences in 10,000-year analyses for the nominal case

- For the human intrusion scenario analyses, the borehole case performed slightly better simply because of the lesser horizontal area that a vertical package represents as compared with the same package laid horizontally

CCDFs of Nominal Cumulative Release (Aqueous and Gaseous) Over 10,000 Years for the Four Cases and for TSPA-91



CCDFs of Nominal Cumulative Release ~~for Animal~~ and Human Intrusion Scenarios, Aqueous Pathway, Composite-Porosity Model, 10,000 Years



Waste Package Design Variations

- M&O addressed the following designs for spent fuel waste packages:
  - Three outer corrosion-allowance material thicknesses
  - Two inner corrosion-resistant material thicknesses
- SNL analyses evaluated the following spent fuel waste packages:
  - Two sizes
  - Two outer-container wall thicknesses

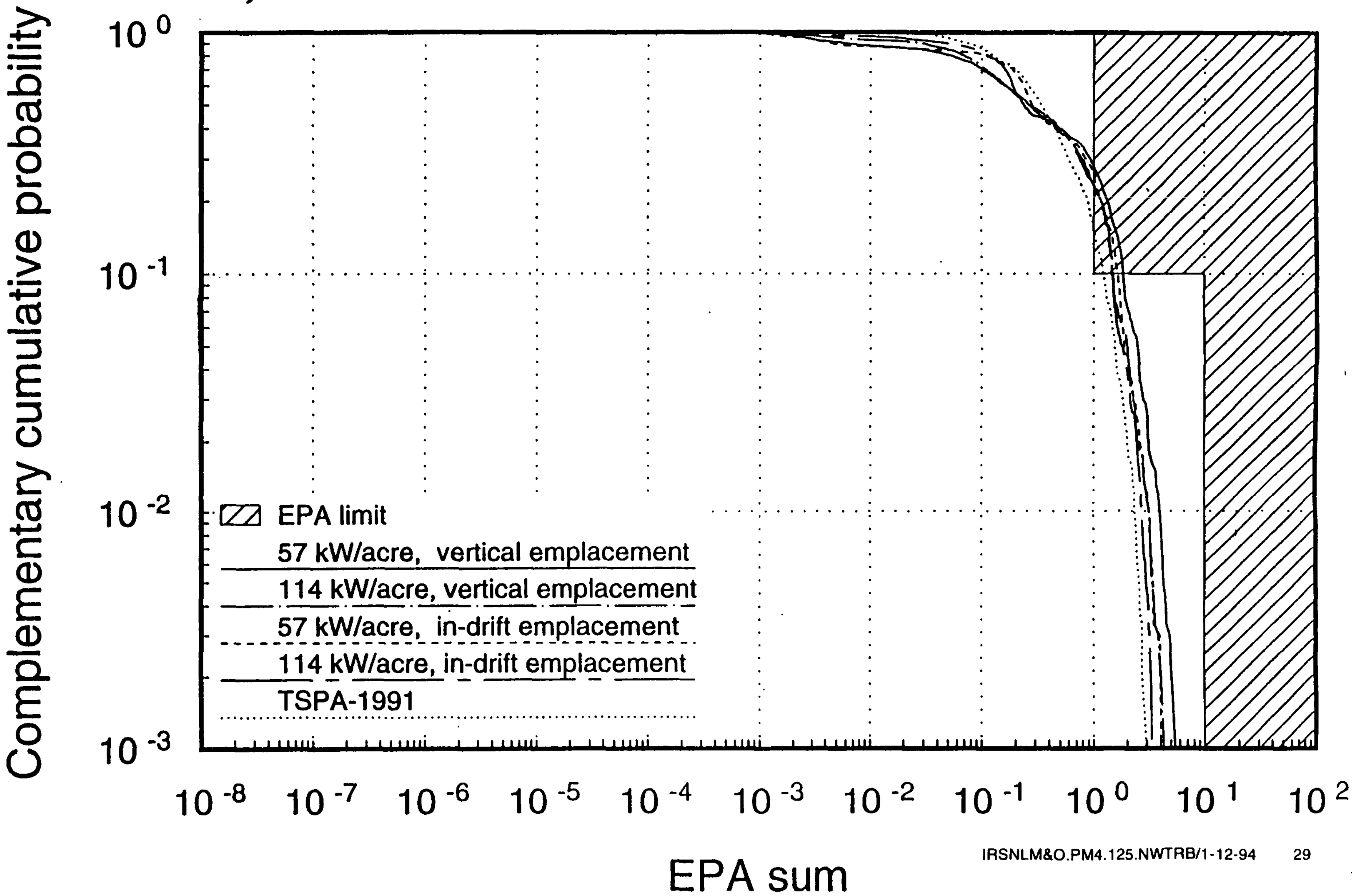
Alternative Designs Investigated in TSPA-93

Design	Alternative Thermal Loads (kW/Ac)		
	28	57	114
Vertical emplacement SCP design alloy 825 @ 0.95 cm		✓	✓
In-drift emplacement MPC mild carbon steel @ 10, 20 or 45 cm alloy 825 @ 0.95 cm and 3.5 cm	✓	✓	✓

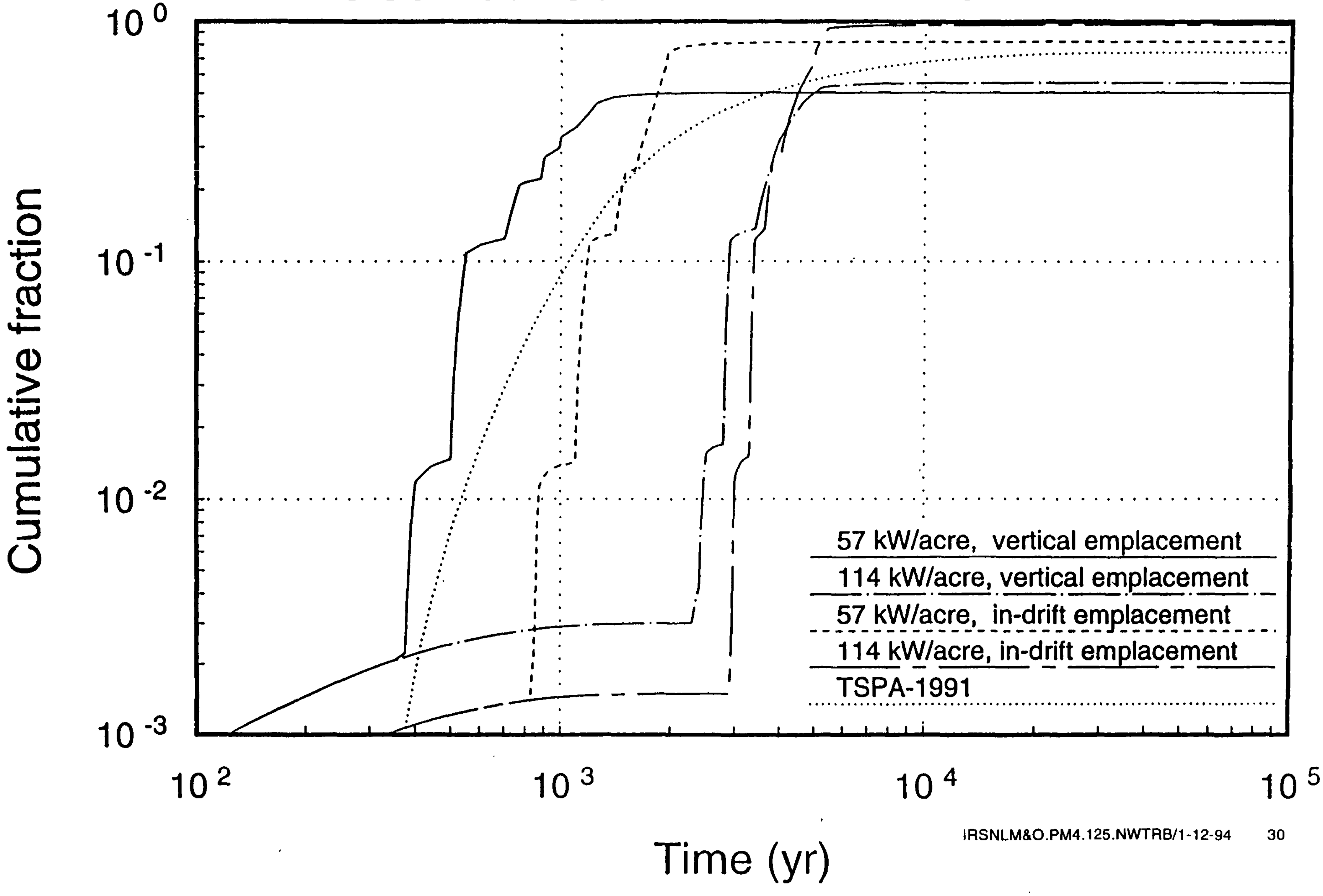
Waste Package Design

- In terms of design, the SNL emplacement mode determined whether or not the waste package was 0.95 cm alloy 825 (borehole) or had an additional 10 cm overpack (in-drift)
  - Although there were differences in cumulative waste-package failure distributions, these differences were not significant in terms of 10,000-year cumulative releases
- M&O analyses addressed additional overpack thicknesses of 20 and 45 cm, and for the 10 cm case, a thicker inner barrier (3.5 cm)
  - Only the 45 cm mild steel overpack had a significant impact on performance up to 100,000 years

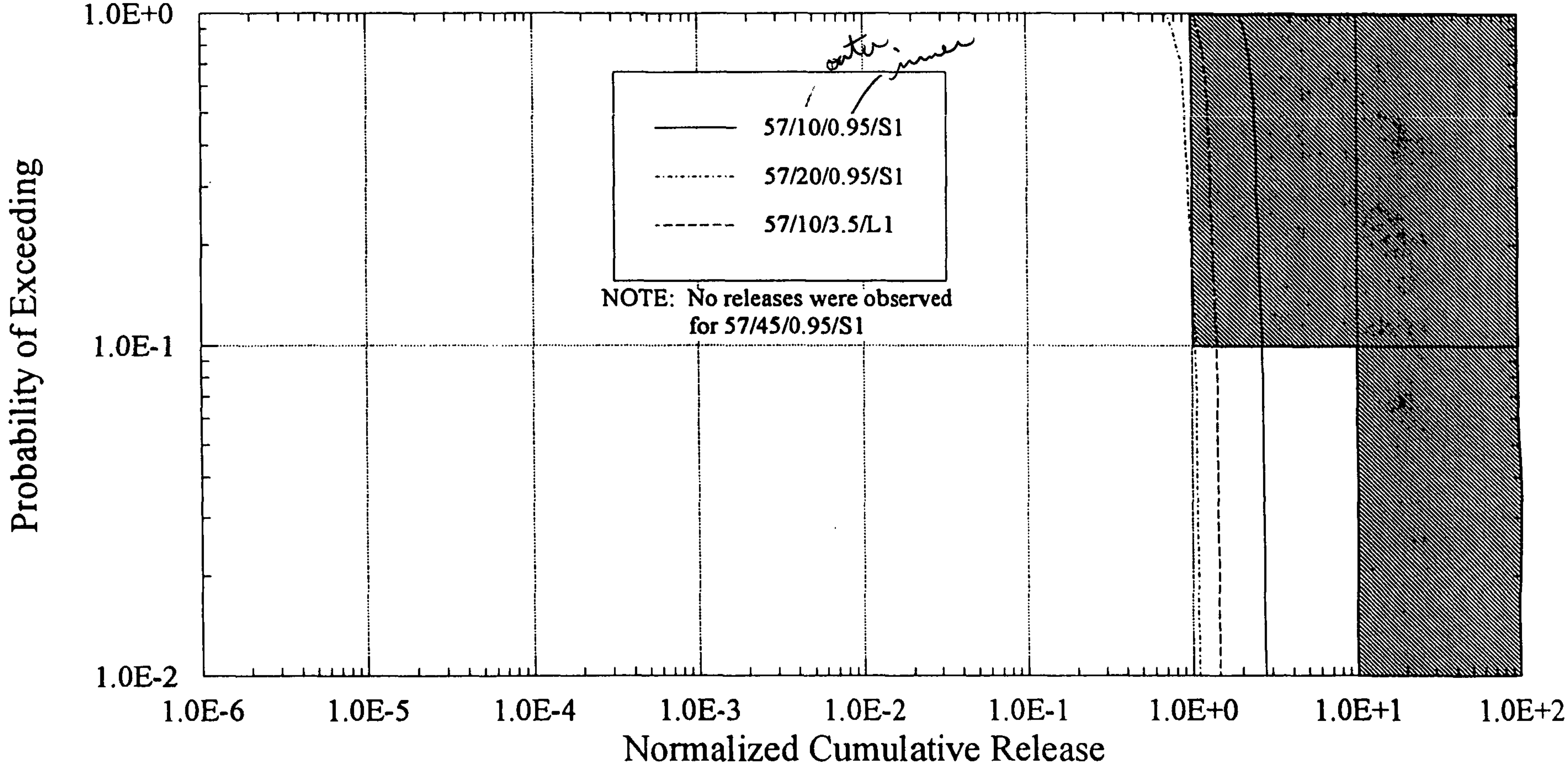
CCDFs of Nominal Cumulative Release (Aqueous and Gaseous) Over 10,000 Years for the Four Cases and for TSPA-91



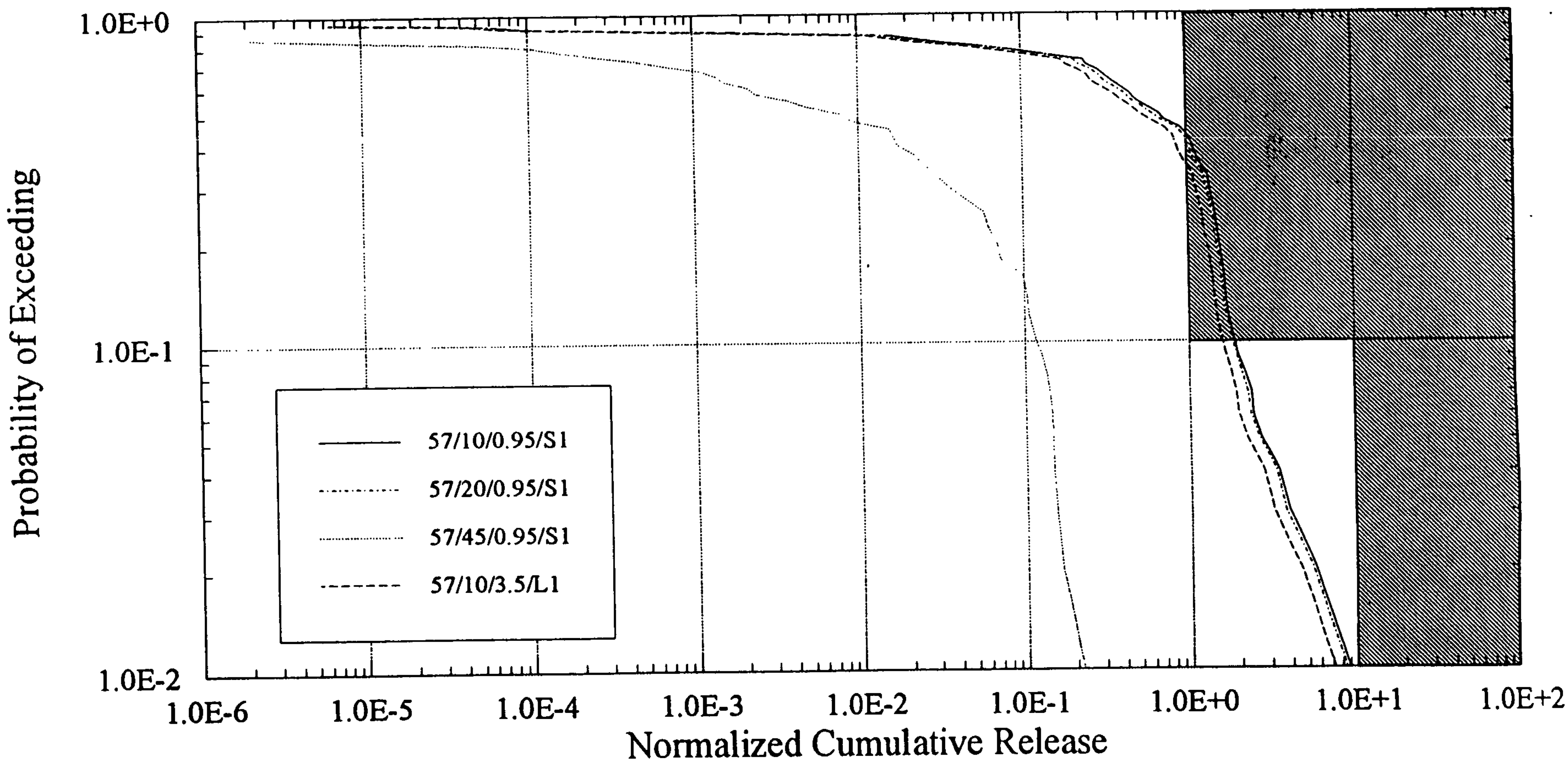
Distribution of Container-Failure Time for the Four Cases and for TSPA-91



Container Thickness--100 Realizations at 10,000 Years:
CCDF of Releases to the AE at 10,000 Years



Container Thickness--100 Realizations at 100,000 Years:
CCDF of Releases to the AE at 100,000 Years



General Compliance

Compliance with 40 CFR Part 191 and 10 CFR Part 60

- The Environmental Protection Agency's general environmental standard (not currently applicable to Yucca Mountain)
  - Aqueous releases generally were five orders of magnitude below requirements
  - Gaseous releases of C-14 generally violated requirements
- The Nuclear Regulatory Commission's 10 CFR 60.112 engineered barrier system requirements were not evaluated in TSPA-93

Dose versus Complementary Cumulative Distribution Function (CCDF)

- Are insights different?

Significance of Parameters for Release and Dose Results

- Key site issue is conceptual model for flow and transport through fractured-porous media and the magnitude of unsaturated zone percolation flux

- Most analyses of the hydrologic flow regime in the unsaturated zone (whether ambient or thermally perturbed) assume composite porosity flow model

- Validity of this assumption and its impact on predicted performance should be more rigorously evaluated

Significance of Parameters for Release and Dose Results

(Continued)

- The representation of the possible increase in flux that may be attributable to future climate changes is uncertain and important to either result
- Secondary effects of climate change: increased saturated zone flux and mixing depth are important to dose
- Doses from gaseous release of C-14 to accessible environment not evaluated in terms of dose in TSPA-93

Dose versus Complementary Cumulative Distribution Function (CCDF)

Technical Challenges of Dose Calculations

Saturated Zone is of Particular Significance to Dose Results

- **Aqueous release to accessible environment relatively insensitive to flow in the saturated zone**
  - Unsaturated zone travel-time long compared to saturated zone travel-time
- **Doses from aqueous releases at the accessible environment directly related to the flux through the saturated zone**
  - If a dose-based standard is promulgated, a greater understanding of the saturated zone will be required

Biosphere Modeling Necessary for Definitive Dose Calculations

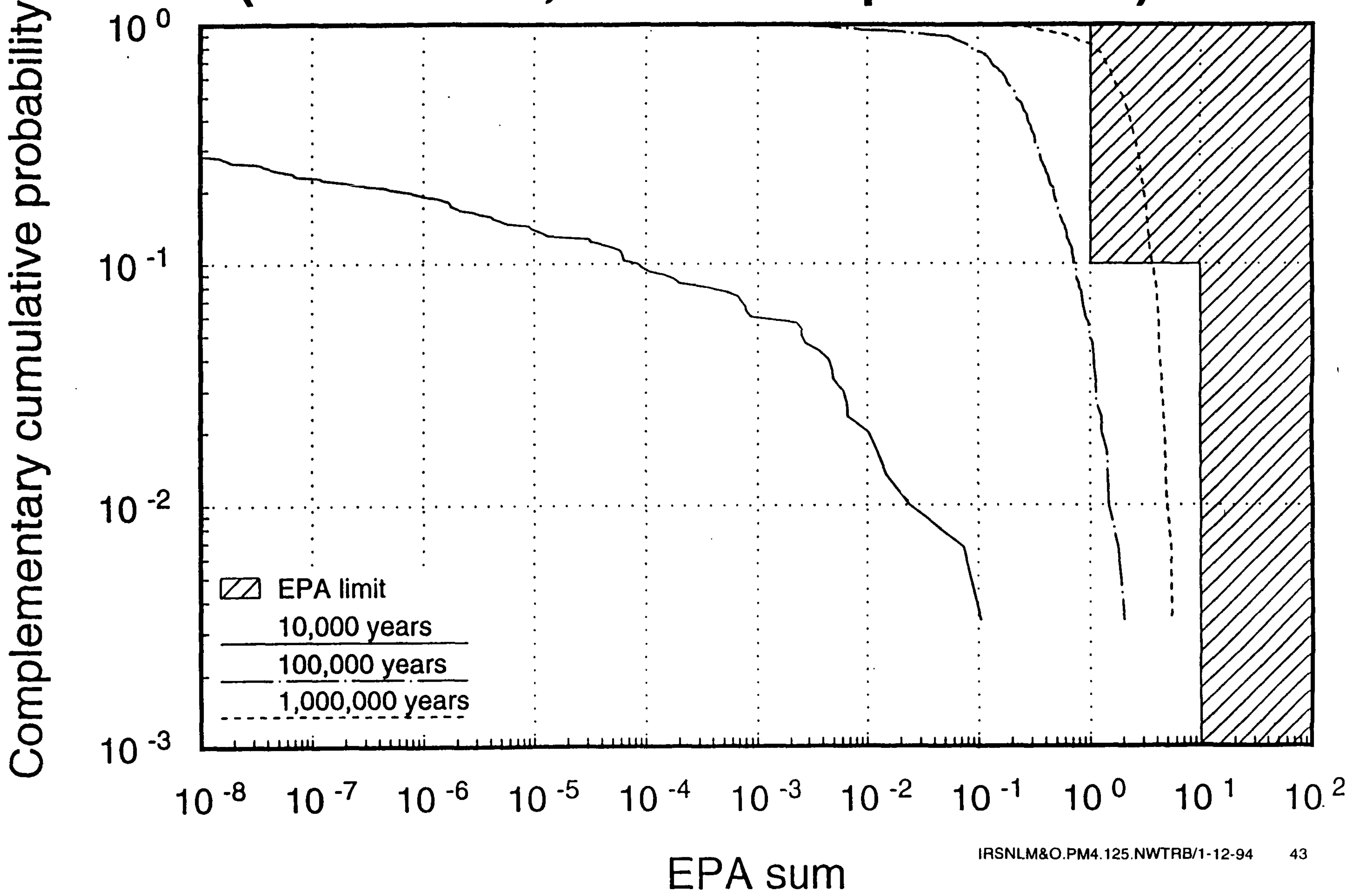
- Biosphere modeling needs to address climate change and human development
- Reference biospheres specific to Yucca Mountain, over time, would be needed
- A comprehensive list of features, events, and processes (FEPs) of relevance for biosphere modeling would need to be developed
- Defensible method must be used for screening and combining FEPs into biosphere models
- There may be greater uncertainty in long-term biosphere modeling than in geosphere modeling

Performance Period

Reasons for Conducting Analyses Over Time-Periods Greater than 10,000 Years

- Evaluate consequences associated with long-lived radionuclides not released in 10,000 years
- Provide "better insight on the long-term performance of disposal alternatives"
- Compare results with other countries that consider dose over longer time-periods
- Prepare for discussions with the National Academy of Sciences Committee on the Review of Applicable Standards for Yucca Mountain

Distribution of Cumulative Aqueous Release (57 kW/acre, vertical emplacement)



When Considering the 10,000 Yr Time-Period

- Virtually all (greater than 99.99%) of the release to the accessible environment is the result of C-14
- Cumulative aqueous release to the accessible environment has about a 90% probability of being less than 10^{-6} of the EPA limit
- Aqueous releases are generally insignificant over 10,000 years, but are very sensitive to the percolation flux and the conceptual model for fracture-matrix interaction

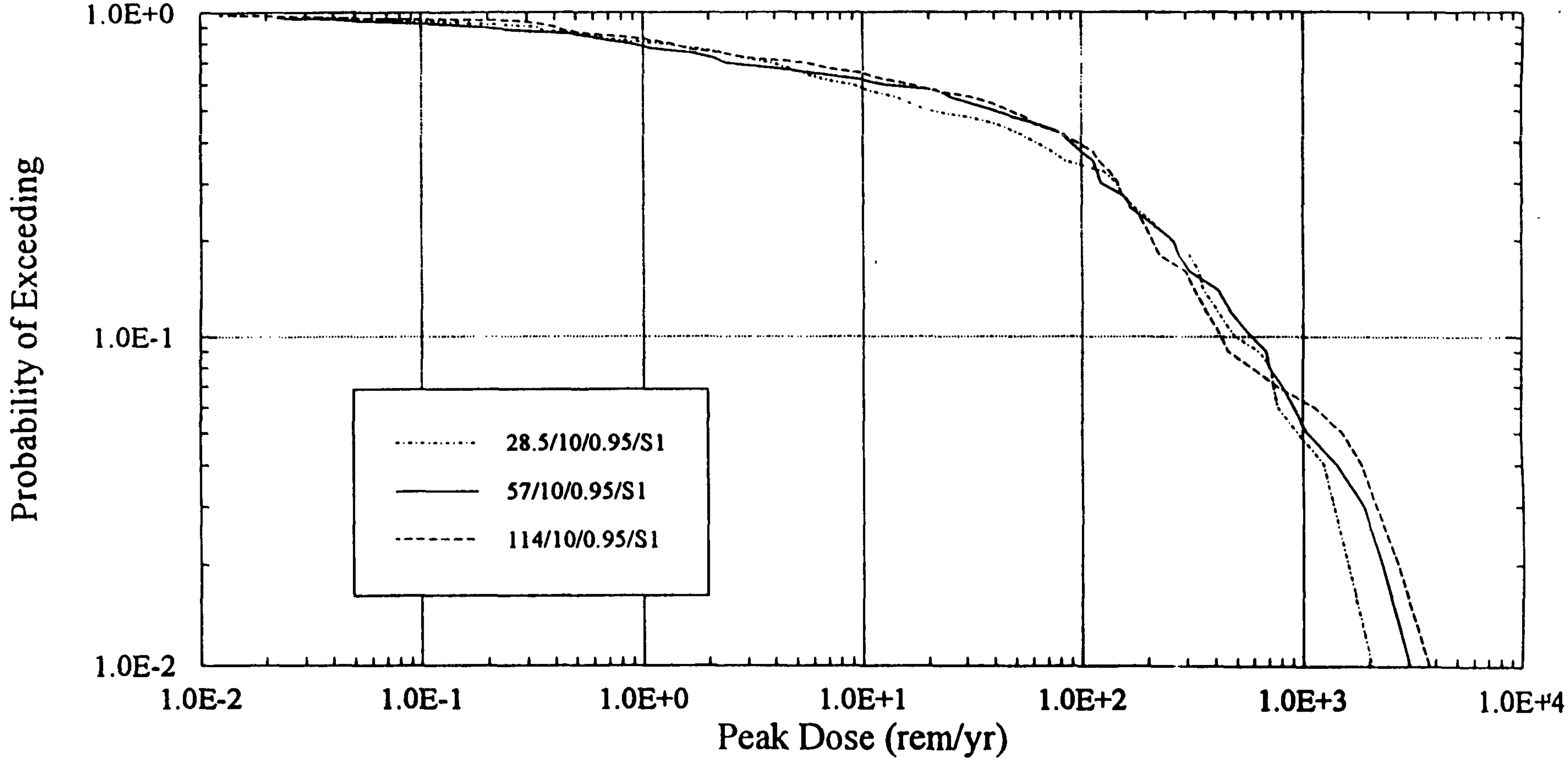
For the 100,000 Yr Time-Period

- Gaseous release accounts for half of total release
- Remainder is provided by unretarded aqueous species, primarily ^{99}Tc
- Generally, cumulative aqueous radionuclide release over 100,000 years is insensitive to the thermal load and outer barriers less than 20 cm
- Outer barriers on the order of 45 cm, especially when combined with low thermal loads, yield 100,000 yr waste package

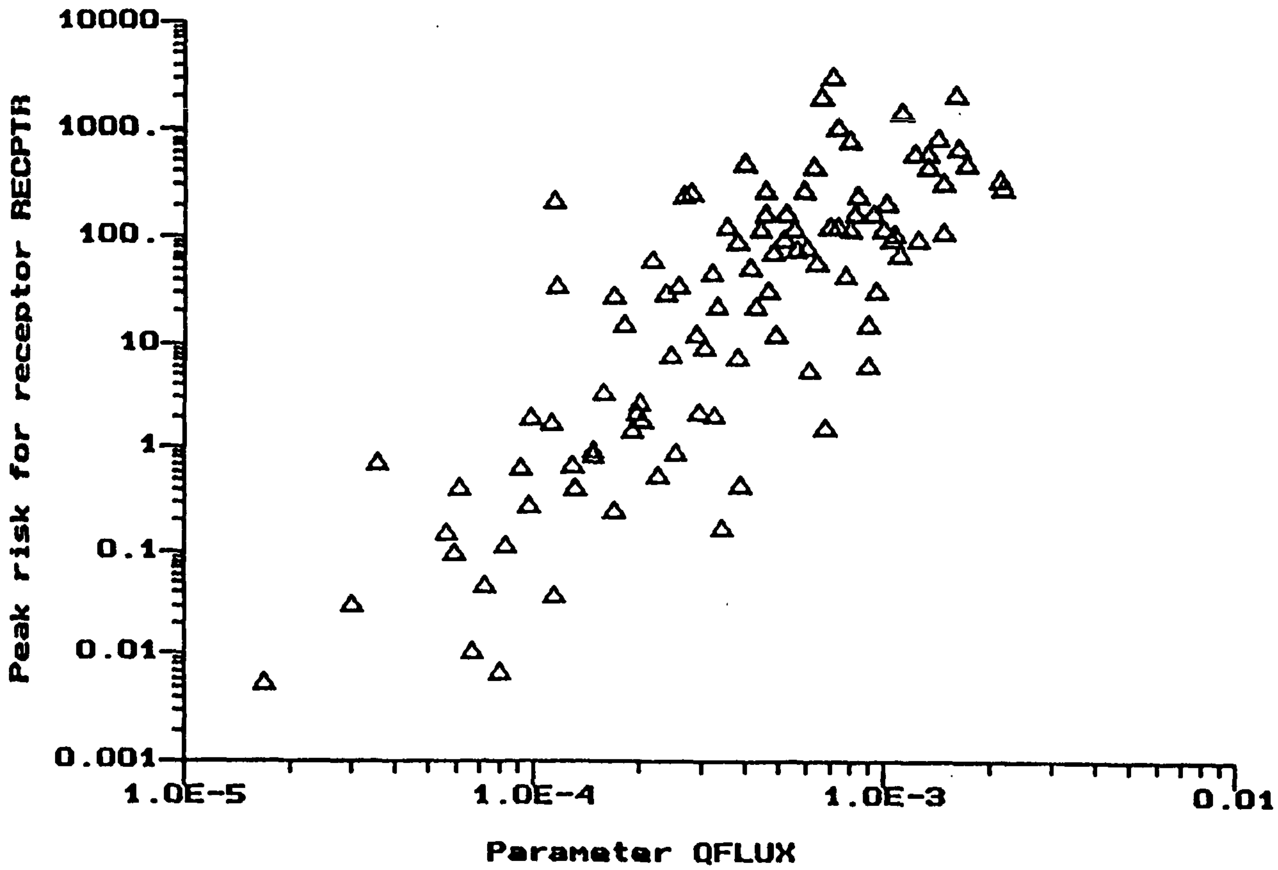
Doses Over the 1,000,000 Yr Time-Period

- Peak doses generally attributable to ^{237}Np
- Where this is not the case, either there is low flux through the unsaturated zone, high Np retardation, or low Np solubility
- Peak dose over 1,000,000 years is insensitive to thermal loads and waste package design
- Peak dose is sensitive to saturated-zone mixing depth
- Dose also sensitive to dose-conversion factors

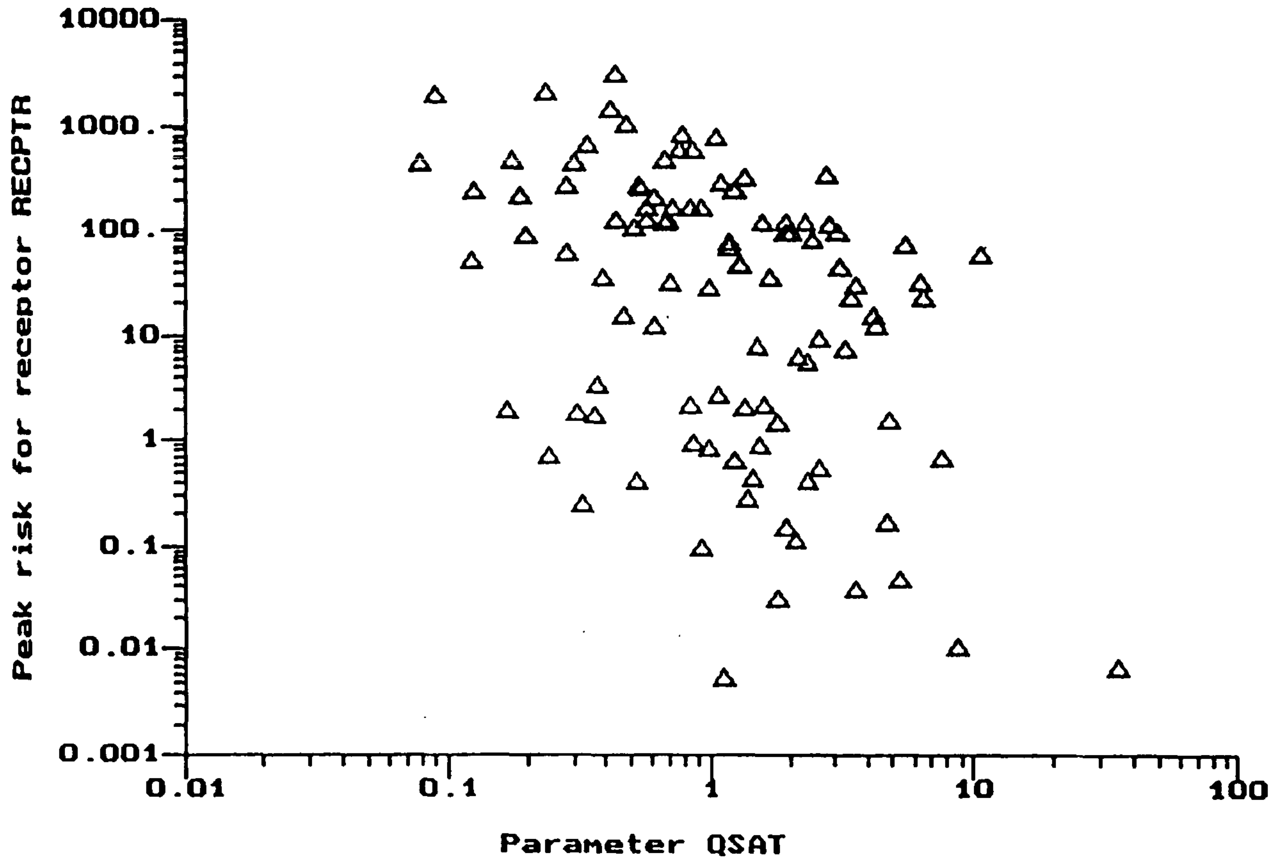
Peak Dose up to 1,000,000 Yrs: Alternate Thermal Loads



Sensitivity of Peak Dose to Percolation Flux



Sensitivity of Peak Dose to Saturated Zone Flux



Appendix

Common and Contrasting Approaches in TSA and RIP for TSPA-93

- Often, the two codes used the same conceptual approach, but implementation differed in details
- Common: one-dimensional approximation of unsaturated zone flow and transport problem, with implementation contrasts
  - TSA used 8 and 5 flow tubes, respectively, for modeling releases from representative locations for the lower and higher therma-loading cases
  - RIP used 9 flow tubes to model releases from spent fuel and high-level waste containers

Common and Contrasting Approaches in TSA and RIP for TSPA-93

(Continued)

- Common: Composite-porosity conceptual model, with implementation contrasts:
  - TSA is capable of invoking a separate "Weeps" fracture-flow conceptualization, with no matrix flow
  - TSA assumed fracture flow when the flux value of an iteration exceeded a probabilistic value of Topopah Spring saturated matrix conductivity
  - RIP allowed matrix flow to continue regardless of flux
  - TSA used slightly higher dispersion values than RIP

Common and Contrasting Approaches in TSA and RIP for TSPA-93

(Continued)

- Common: Exponential initial infiltration distribution with a mean of 0.5 mm/yr with implementation contrasts:
  - TSA wetter climate, with a probability of 1 over 100,000 yrs, multiplies initial distribution by 20
  - RIP wetter climate, a linear increase culminating in a 3-fold multiplication of the initial distribution

Common and Contrasting Approaches in TSA and RIP for TSPA-93

(Continued)

- **Common: Saturated-zone flow and transport modeling basis, with implementation contrasts:**
  - TSA used the midpoint of breakthrough curve arrival times in SNL three-dimensional saturated-zone flow and transport analyses to calculate effective velocities
  - RIP directly used velocities from the same SNL calculations
  - TSA sampled from an linear distribution of vertical mixing depths from 10 to 500 m
  - RIP used a single value of 50 m

Common and Contrasting Approaches in TSA and RIP for TSPA-93

(Continued)

- Common: Radionuclide solubilities and distribution-coefficients with implementation contrasts:
  - TSA: distribution used as obtained from expert elicitation
  - RIP: solubility distributions corrected for temperature and pH
- Common: Gas flow and transport modeling basis (work by Ross, under SNL contract), with no significant implementation contrasts
- Common: Dose modeling basis (conversion factors used in TSPA-91) with no implementation contrasts

Common and Contrasting Approaches in TSA and RIP for TSPA-93

(Continued)

Near-field implementation contrasts:

- **Inventory for aqueous release**
  - TSA: 8 radionuclides adjusted for ingrowth prior to analysis (no chains)
  - RIP: 39 radionuclides; 4 decay chains
- **Aqueous release and transport**
  - TSA: release dependent on spatially variable flux
  - RIP: release diffusion controlled, activated by liquid saturation of >8%

Common and Contrasting Approaches in TSA and RIP for TSPA-93

(Continued)

Very near-field characteristics contrasts:

- TSA: backfill, higher temperatures, dry oxidation
- RIP: no backfill, lower temperatures, no dry oxidation
- TSA: if temperature > 100°C, no liquid water, no corrosion
- RIP: liquid water present above 100°C, corrosion if liquid saturation >8% (sensitivity studied)
- TSA: pitting corrosion rate defined by mean of higher of three growth rate LLNL distributions
- RIP: pitting corrosion rate varied over the range of the middle of these same three distributions

Common and Contrasting Approaches in TSA and RIP for TSPA-93

(Continued)

- M&O TSPA-93 did not consider human intrusion or volcanic disruption
- SNL TSPA-93 did consider human intrusion and volcanic disruption
- SNL and M&O relied on input from data interpretation and detailed modeling conducted by other participants, including LLNL, LANL, USGS, SNL, and M&O