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

NUCLEAR WASTE TECHNICAL REVIEW BOARD FULL BOARD MEETING

SUBJECT: COMPARISON OF TOTAL SYSTEM PERFORMANCE ASSESSMENT RESULTS

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Outline

- Purpose and scope of Total System Performance Assessment (TSPA) 1991
- Comparisons of models and analyses
- Total system CCDF
- Lessons learned

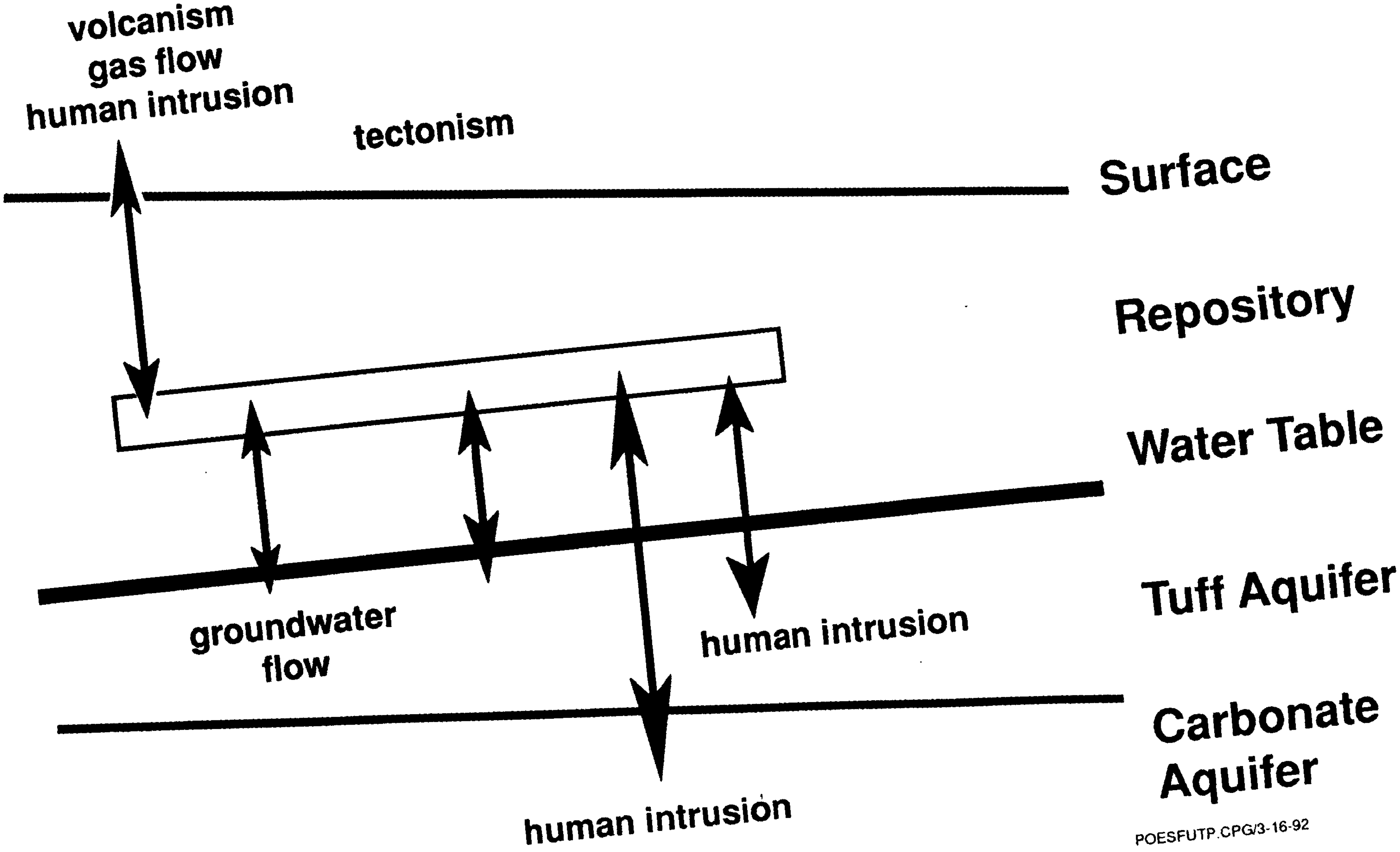
Purpose of Total System Performance Assessment (TSPA) 1991

- Help develop an "abstraction" process necessary for future total-system performance assessments
- Compare results from two different modeling approaches
- Demonstrate production of an estimate of system performance using a Complementary Cumulative Distribution Function (CCDF)

1991 TSPA

- Stochastic simulations
- Doses
- The saturated zone (SZ) to the accessible environment
- Gas transport through the unsaturated zone (UZ)
- Release pathways including human intrusion, volcanism, and tectonism
- Detailed source term
- Complementary ~~C~~CDFs

Release Pathways



volcanism
gas flow
human intrusion

tectonism

Surface

Repository

Water Table

Tuff Aquifer

groundwater
flow

human intrusion

Carbonate
Aquifer

human intrusion

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TSPA 1991 Goals and Limitations

- The goal of TSPA is to combine estimates of engineered system behavior and fluid and transport in the geosphere to evaluate total system performance (i.e., CCDF)
- This exercise was not comprehensive in terms of components modeled and used conceptual models not completely justified at this stage
- These analyses are not adequate to support formal higher-level suitability findings

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The Source Term Models

- The PNL and LLNL/SNL source-term models were comparable
  - Container failure rates were sampled from assumed distributions (but differing distributions were used)
  - Flow-through and wet-continuous water/waste contact modes were modeled
- PNL considered releases from the high-level waste glass and spent fuel waste forms
- SNL assumed spent fuel inventories only

Saturated-Zone Ground-Water Flow Modeling

- The <u>saturated-zone</u> models of both SNL and PNL were based on an equivalent porous medium conceptualization
  - PNL used two-dimensional stochastic representations of the carbonate and tuff aquifers
  - SNL used a one-dimensional stochastic representation of the saturated-zone using averaged properties

Unsaturated-Zone Ground-Water Flow Modeling

- In the <u>unsaturated-zone</u>, both PNL and SNL used an equivalent continuum model with the fracture properties incorporated in the relative permeability and capillary pressure curves
  - PNL used a deterministic two-dimensional vertical slice through the repository with a single fault zone
  - SNL used six one-dimensional stratigraphic columns from the repository to the water table, with flow simulated stochastically 300 times for each column
  - SNL also used a simplified discrete fracture representation (the "Weeps" model) to define (a) the percent of waste packages potentially providing a source for far-field transport, and (b) the advective velocity from the repository to the water table

Flux/Percolation Assumptions

- Five flux cases (0, 0.01, 0.05, 0.1 and 0.5 mm/yr) were analyzed by PNL as part of the undisturbed-case analyses
- SNL assumed a range of percolation rates (0.0 through 39 mm/yr)
  - An exponential distribution with a mean of 1.0 mm/yr assured that stochastic sampling was weighted toward lower values
  - The range allows values to be stochastically selected that could be possible under climate-change conditions
  - The range ensures that calculations reach the transition from matrix-dominated flow to fracture-dominated flow

Flux/Percolation Conclusions

- Neither PNL nor SNL composite porosity model calculations at lower flux rates resulted in radionuclide transport into the saturated zone
- SNL's higher-flux realizations led to radionuclide transport to the accessible environment

Gas Flow Modeling

- Temperature, pressure, and humidity differences were assumed to drive flow of ^{14}C from the repository to the surface
- A series of two-dimensional steady-state simulations was used by SNL to produce gas transit times as a function of temperature, and a transient calculation was performed by PNL
- Because travel times were relatively short, the source-term model's release rate of ^{14}C was an important determinant of the cumulative release over 10,000 years
- Differences between PNL and SNL results are directly related to the three order-of-magnitude differences in the assumed permeabilities

Human Intrusion Assumptions

- If a driller hit a container, up to the entire content could be brought to the surface or released into the saturated zone
- If the driller missed a container, contaminated tuffs were brought to the surface
- In the saturated zone, either the low-flow-rate tuff aquifer or the higher-flow-rate carbonate aquifer was assumed to receive the waste

Human Intrusion Assumptions

(Continued)

- The number of holes was either fixed or input as a distribution
- The timing of a drilling event, whether or not it hit a container, and the amount of waste mobilized were stochastically determined
- The SNL analyses assumed a spent-fuel inventory, and the PNL analyses assumed a mix of spent-fuel and high-level waste glass

Results of Human Intrusion Analyses

- Results defined the more important parameters
  - The frequency of drilling was important to the magnitude of calculated releases
  - Drilling frequencies in 40 CFR Part 191 guidance resulted in multiple drilling events for the 10,000-year regulatory period
  - Aqueous releases were dependent on distributions of ground-water velocities and retardation coefficients
  - Surface releases had little relation to site characteristics except as drilling frequency, which may be site-specific

Basaltic Igneous Activity Modeling

- The conceptualization modeled was a dike that intrudes along a plane behind an upward propagating stress crack and entrains waste as it flows up, releasing waste to the surface
- Numerous trials were used to simulate various dike widths, lengths, and orientations
- Dike length and width were important parameters in determining the release
- The SNL analysis used published estimates specific to Yucca Mountain for recurrence rates and descriptions of the mechanics of intrusion
- The PNL analysis was based on interpretations of literature not specific to Yucca Mountain but produced similar results

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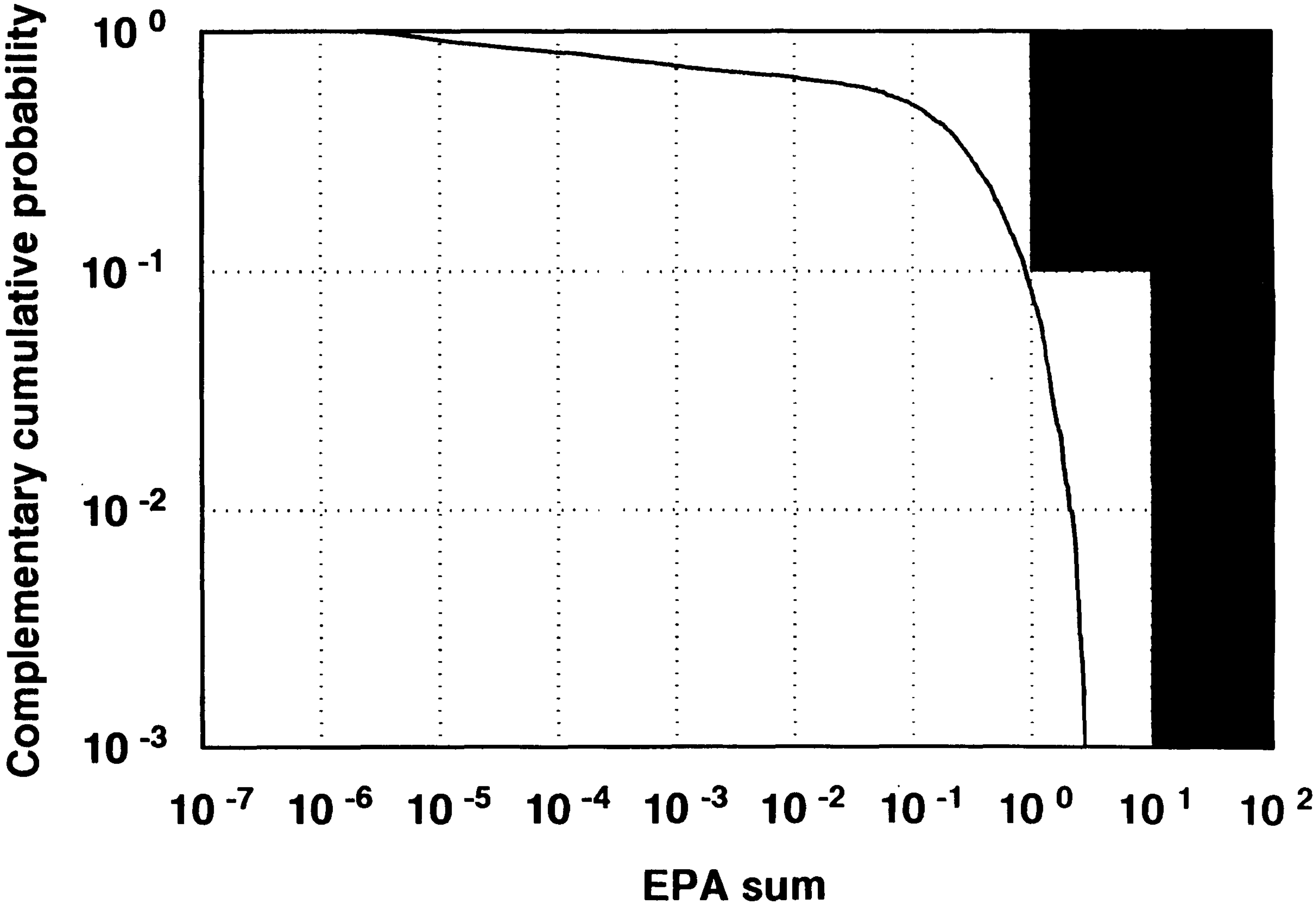
The Total System CCDF

- There was no disagreement over how CCDFs may be combined
- CCDFs included scenario probabilities and parameter uncertainties
- Determining scenario probabilities remains an open question

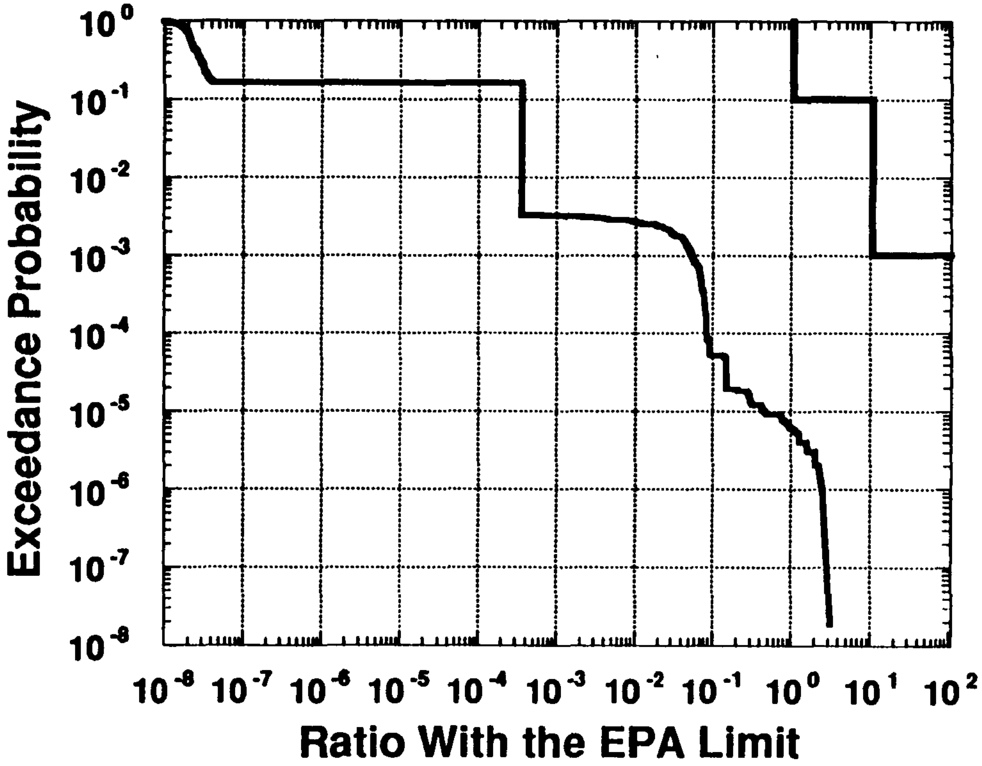
Overall Conditional CCDF for SNL TSPA Assuming 50/50 Composite-Porosity and Weeps



The SNL Total System CCDF

- The overall CCDF was constructed by combining equally weighted contributions of the composite-porosity and "Weeps" models
- Main release contributors were the nominal processes (i.e., aqueous and gaseous flow and transport)
- Disturbances such as human intrusion and volcanism were of lesser importance

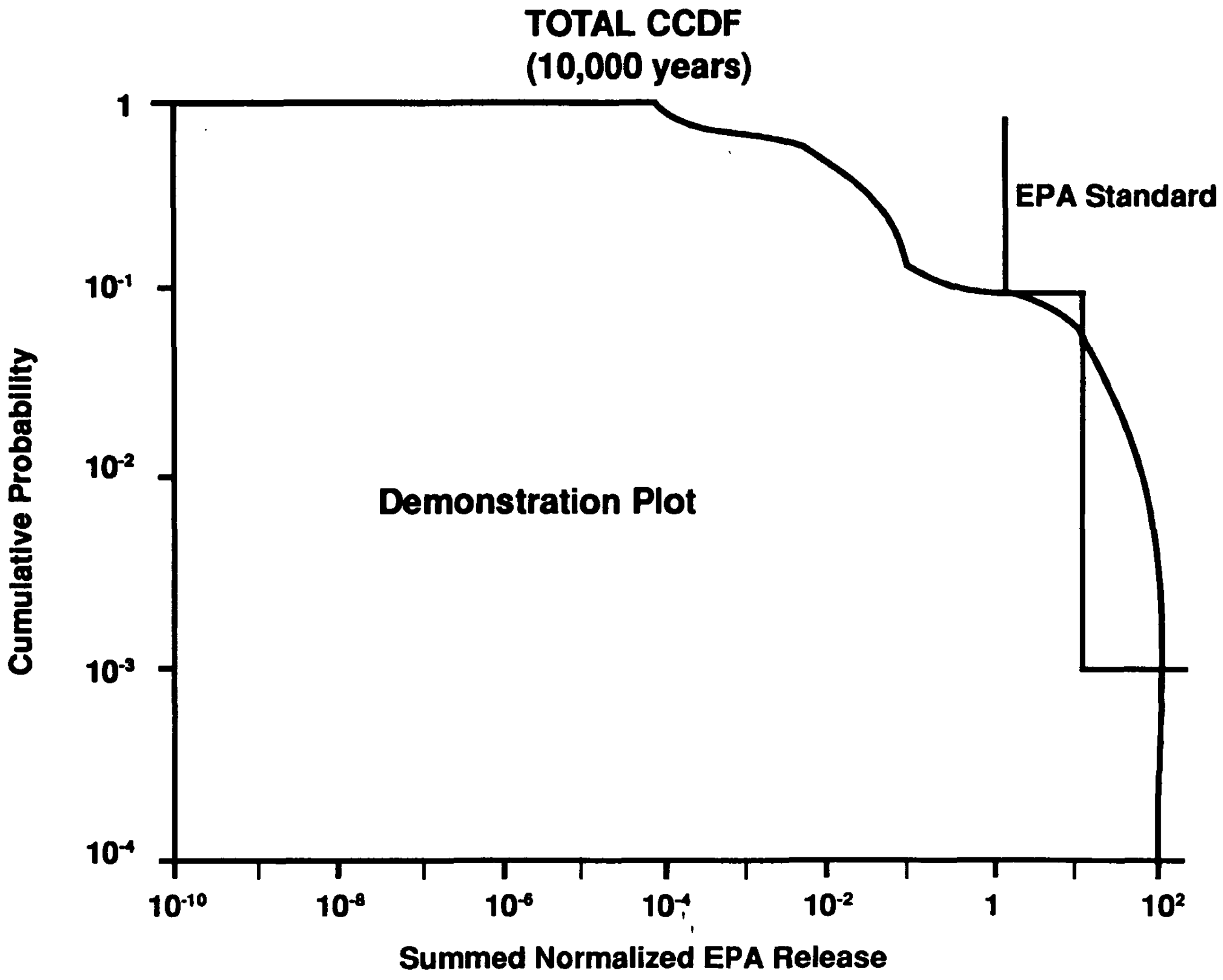
PNL TSPA Results



Components of PNL CCDF

- First: high-probability, low-consequence effects from a driller bringing contaminated tuff to the surface
- Second: release of gaseous carbon-14 as containers fail (base case, gaseous)
- Third: lower-probability, higher-consequence effects from a driller bringing the waste form to the surface or dropping it into the saturated zone (human intrusion, hit)
- Fourth: low-probability, higher-consequence effect of a basaltic dike propagating through the mountain, entraining waste, and bringing it to the surface (volcanism)

U.S. NRC 1990 Total System Assessment Results



The U.S. NRC's 1990 Total System CCDF

- Only aqueous-pathways analyses were included
- Two scenarios dominated the CCDF because of high assigned probabilities:
  - Drilling under non-pluvial climatic conditions (including drilling) (flux 0.1 - 5.0 mm/yr; probability ~0.9)
  - Drilling under pluvial climatic conditions (including drilling) (flux 5.0 - 10.0 mm/yr; probability ~0.1)
- Drilling frequency was as specified in 40 CFR Part 191, and drilling brought waste and contaminated rock to the surface
- Drilling did not contribute significantly to the CCDF in terms of consequences, only in terms of high probability

The U.S. NRC's 1990 Total System CCDF

(Continued)

- The non-pluvial case releases were just below the violation points specified by 40 CFR Part 191; pluvial case releases were above those violation points
- Fracture flow was important to determining releases
- Flow vectors at or below a 2 mm/yr infiltration rate did not violate the 40 CFR Part 191 control points on the CCDF

EPRI Performance Assessment, Phase 2
General Features

- Estimate releases from hydrologic and gaseous pathways, volcanoes, and human intrusion
- Use one expert to designate input for each scientific and engineering field
- Represent uncertainties in knowledge, models, and data with discrete distributions (discrete values and probabilities)

EPRI Performance Assessment, Phase 2 General Features

(Continued)

- Use logic trees as tools to specify inputs and to organize release calculations for all combinations of uncertain models and parameters
- Calculate CCDFs of release from probability of each combination of models and parameters and from release given that combination
- Calculate releases for 13 nuclides (including gaseous release of C-14)

EPRI Performance Assessment, Phase 2
Improvements from Phase 1

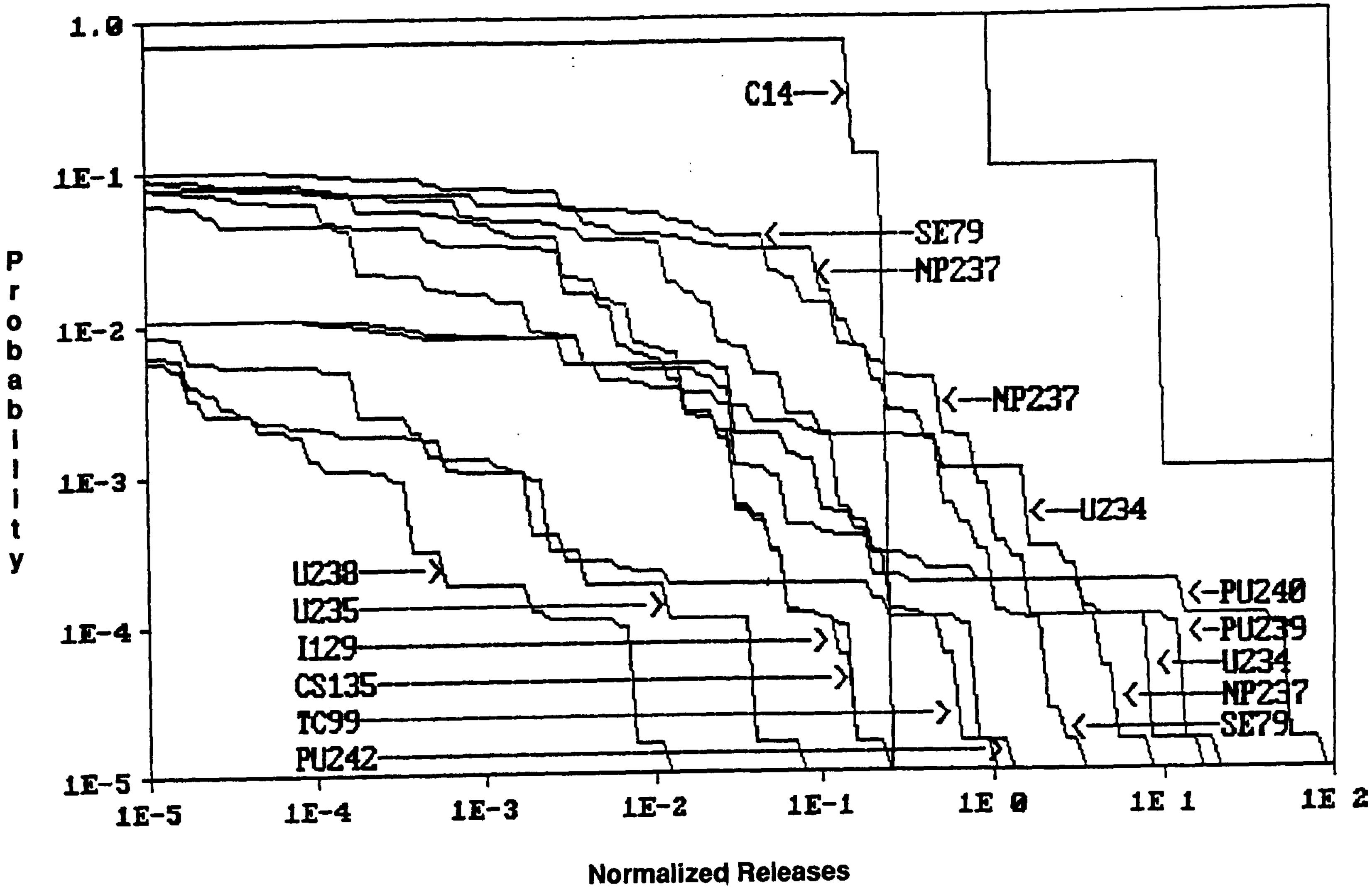
- Surface-water model accounts for precipitation-infiltration interface using site-specific soil and topography
- Source-term model includes unsaturated, wet-drip, and saturated conditions and accounts for both matrix dissolutilon rate and elemental solubilities
- Hydrological flow model, while still simple, accounts for two layers (Topopah Spring and Calico Hills units) and models non-stationary flux; it has been verified with more detailed codes (TOSPAC)

EPRI Performance Assessment, Phase 2 Improvements from Phase 1

(Continued)

- EBS model is application of Weibull Distributions for specific EBS designs (type 304L stainless, alloy 825, and multiple barrier systems) that can be revised for other specific designs
- Gaseous release of C-14 incorporates detailed gas flow calculations for a range of possible repository temperatures
- Human intrusion model considers drilling with water table contamination, drilling with surface contamination, and excavation; and it has a general format that can be revised or extended for further applications

CCDFs for 12 Nuclides Released by Gaseous and Aqueous Pathways



EPRI Performance Assessment, Phase 2
Specific Conclusions

- Hydrologic pathways lead to the largest releases for high levels of release
- Gaseous release of C-14 is the predominant contributor, if releases are low
- Volcanoes, earthquakes, and human intrusion do not appear to lead to large releases

EPRI Perfomance Assessment, Phase 2
Specific Conclusions

(Continued)

- Largest releases are associated with unlikely combinations of large fluxes, no diversion of ground-water flow, flooding of part of repository, and high solubilities and dissolution rates

- At lower levels of release, EBS design, fracture-matrix coupling, and diversion of ground-water flow affect estimated releases

- Factors that are less influential are thermal pulse and potential borehole fractures (failure of the air gap)

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Lessons Learned

- A comprehensive, standard set of data and assumptions is a crucial need for future TSPAs
  - Communication of system data and specifications is made difficult when different models are involved
  - Where different conceptual models or levels of modeling detail are involved, data-transfer must include a comparison of the assumptions represented by that data
- Bounding models and their high-release results reflected current uncertainty in conceptual models and data sparsity
  - Site-specific data from the Site Characterization Program can help selection of more realistic conceptual models and of more realistic parameter distributions

Lessons Learned

(Continued)

- **Activities were identified that could be completed without additional site data**
  - Current conceptual models could be used to evaluate effects of parameter uncertainty
  - New analyses could be designed to test the importance of conceptual model and process uncertainty
- **Performing a total system analysis includes comprehensive review of assumptions and data**
- **The objectives of this TSPA were achieved: (a) demonstrating capability, (b) generating CCDF curves, and (c) expanding beyond the Performance Assessment Calculational Exercises of 1990**

Lessons Learned

(Continued)

- Results of this TSPA have limited use in programmatic decision-making
  - The ^{14}C calculations were applicable to any unsaturated site
  - The results of the gaseous pathway release calculations suggest consideration of a more robust engineered barrier system in order to satisfy current regulations
  - Major radionuclides of concern with respect to aqueous release are the fission products

Design and Site Information Needs Emphasized by TSPA 1991

- A firm waste-package design and emplacement concept are needed to allow a performance assessment baseline calculation
- A statistically meaningful set of hydrologic properties data is needed for all important stratigraphic units
- Data are needed on a scale comparible to the modeling
- Geochemical data are needed, including modifications expected from the thermal changes