SAND2007-6277P

Performance Assessment Methodologies: Statistical Methods and Regulatory Requirements

KHNP Training Program
Module 6: Assembly of a Safety Case

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Outline

I. Overview of This Week's Topics

II. Calculation of Normalized Releases

III. Release Limits

IV. Statistical Regulatory Requirements

V. Summary

Overview of This Week's Topics

Overview of This Week's Topics

- Training at CEMRC has provided a general understanding of statistical techniques, theory, and approaches for dealing with uncertainty
- This week provides insight into what specific techniques and methodologies are applied for WIPP PA

Overview of This Week's Topics (cont'd)

- Day 1: Regulations (Eric Vugrin)
  - Calculation of Normalized Releases: how and why
  - Release Limits
  - Statistical Regulatory Requirements
- Day 2: Probabilistic Modeling (Eric Vugrin)
  - Probabilistic PA Framework
  - Dealing with Uncertainty
  - Incorporating Deterministic and Probabilistic Modeling
  - Sampling

Overview of This Week's Topics (cont'd)

- Day 3: Parameters (Mario Chavez)
  - Development
  - Database
- Day 4: Numerical Codes & Results (Tom Kirchner)
  - Stochastic Modeling
    - LHS
    - CCDFGF
  - Sensitivity Analysis
    - STEPWISE

Releases and Scenarios

- Calculation of releases differs for the two types of scenarios for which WIPP is regulated
  - Undisturbed performance
    - "Annual effective dose" is reported in terms of millirems (microsieverts) per year
    - This type of dose calculation is typical of risk assessments
  - Disturbed performance
    - "Normalized releases" are reported
    - This type of release calculation is rather unique to the WIPP

Calculation of Normalized Releases

Releases are normalized by radionuclide and by the total inventory

$$R = \sum \frac{Q_i}{L_i} \left(\frac{1 \times 10^6 \, curies}{C} \right)$$

R = Normalized release in "EPA units"
Q_i = 10,000-year cumulative release (in curies) of radionuclide *i*
L_i = Release Limit for radionuclide *i*
C = the total transuranic inventory (in curies of α emitters w/halflives > 20 years)

Calculation of Normalized Releases (cont'd)

- **Key Radionuclides in Release Calculations**
  - **Various plutonium isotopes (Pu-239, Pu-240, etc.)**
  - **Am-241**
  - **Various uranium isotopes (U-233, U-234, etc.)**
  - **Various Th isotopes (Th-229, Th-230, etc.)**

Calculation of Normalized Releases (cont'd)

$$R = \sum \frac{Q_i}{L_i} \left(\frac{1 \times 10^6 \, curies}{C} \right)$$

Calculation of Normalized Releases (cont'd)

- Q_i
  - 10,000 year cumulative release for isotope i
  - Release predicted by PA calculations
  - Represents summed release over all release mechanisms
    - Cuttings
    - Cavings
    - Spallings
    - Direct Brine Releases (DBRs)
    - Releases from the Culebra
- WIPP PA models used to calculate releases by each pathway will be discussed next week

Calculation of Normalized Releases (cont'd)

$$R = \sum \frac{Q_i}{L_i} \left(\frac{1 \times 10^6 \, curies}{C} \right)$$

Calculation of Normalized Releases (cont'd)

- L_i
  - Release limit per 1000 metric tons of heavy metal (MTHM) or other unit of waste
  - Varies by radionuclide because the impact on health for a specified mass varies by radionuclide
    - Radionuclides with more adverse health effects have lower L_i

Release Limits (Table 1, App. A of 40 CFR 191)

Radionuclide	L_i (per 1000 MTHM)
Am-241, -243	100
C-14	100
Cs-135, -137	1000
I-129	100
Np-237	100
Pu-238, -239, -240, -242	100
Ra-226	100
Sr-90	1000
Tc-230	10000
Th-230, -232	10
Sn-126	1000
U-233,- 234, -235, -236, -238	100
Other α-emitter w/half-life > 20 years	100
Non-α-emitter w/half-life > 20 years	1000

Calculation of Normalized Releases (cont'd)

$$R = \sum \frac{Q_i}{L_i} \left(\frac{1 \times 10^6 \, curies}{\boxed{C}} \right)$$

Calculation of Normalized Releases (cont'd)

- C
  - Total transuranic inventory of α-emitters w/half lives > 20 years at time of WIPP facility closure (est. 2033)
  - Note that a larger value of C permits a larger release (in curies) while still maintaining compliance

Why are “normalized” releases calculated for disturbed scenarios?

- Normalized releases allow for a comparison between risk of placing waste in WIPP and the risk of never having mined the uranium ores that were processed and ultimately created the TRU waste

Release Limits

Release Limits

- **Undisturbed performance (40 CFR 191.15):**
  - **"Disposal systems for waste and any associated radioactive material shall be designed to *provide a reasonable expectation* that, for 10,000 years after disposal, *undisturbed performance of the disposal system shall not cause the annual committed effective dose, received through all potential pathways from the disposal system, to any member of the public in the accessible environment, to exceed 15 millirems* (150 microsieverts)"**

Release Limits (cont'd)

- **Disturbed performance (40 CFR 191.13)**
  - **"Disposal systems for spent nuclear fuel or high-level or transuranic radioactive wastes *shall be designed to provide a reasonable expectation*… that the cumulative releases of radionuclides to the accessible environment for 10,000 years…**
    - ***Have a likelihood of less than one chance in 10 of exceeding [1 EPA Unit]; and***
    - ***Have a likelihood of less than one chance in 1,000 of exceeding [10 EPA units]*"**

Release Limits (cont'd)

- For disturbed performance, limits vary according to probability level
  - At P=0.1, R must be less than 1 EPA unit
  - At P=0.001, R must be less than 10 EPA units
- Translation: if releases are less than the limits, than the WIPP will be less harmful than if all of the corresponding uranium ore had been left in the ground in a single location and a city with a population of 100,000 people was located directly above that ore

Statistical Regulatory Requirements

Statistical Regulatory Requirements

- **Release limits**
  - **Containment Requirements (40 CFR 191.13) and Individual Protection (40 CFR 191.15)**
  - **Regulations concerning both use the term "reasonable expectation"**
  - **This term does not have a precise legal or statistical definition and its interpretation by the regulator has varied over time**

Statistical Regulatory Requirements (cont'd)

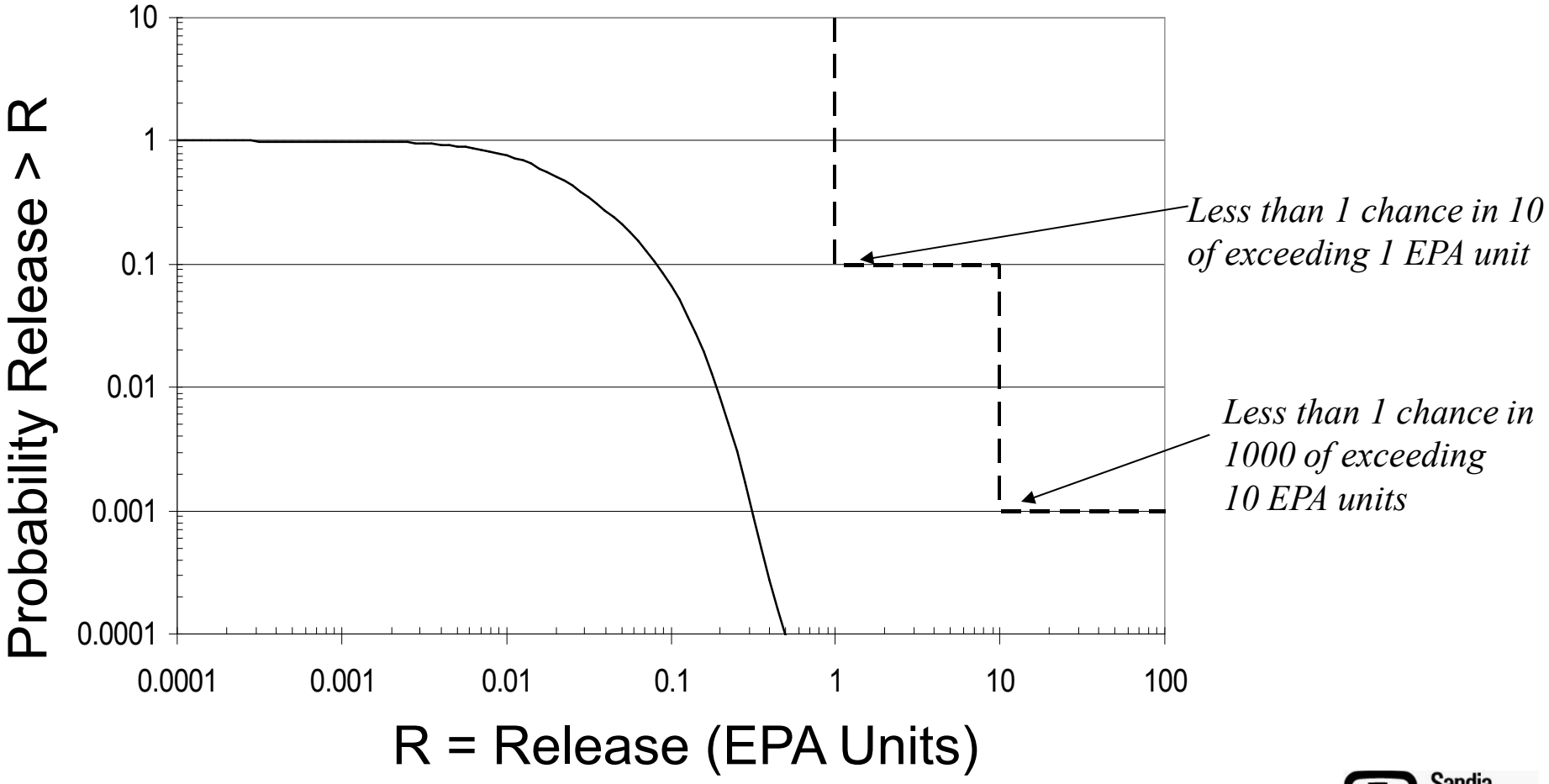
- 40 CFR 191.13 (b): "Performance assessments *need not provide complete assurance* that the requirements of Sec. 191.13(a) will be met. Because of the long time period involved and the nature of the events and processes of interest, *there will inevitably be substantial uncertainties* in projecting disposal system performance. Proof of the future performance of a disposal system is not to be had in the ordinary sense of the word in situations that deal with much shorter time frames. Instead, *what is required is a reasonable expectation*, on the basis of the record before the implementing "

Statistical Regulatory Requirements (cont'd)

- **Results of Performance Assessments (40 CFR 194.34)**
  - **(a) "The results of performance assessments shall be assembled into 'complementary, cumulative distribution functions' (CCDFs) that represent the probability of exceeding various levels of cumulative release caused by all significant processes and events."**

Statistical Regulatory Requirements (cont'd)

Complementary Cumulative Distribution Function



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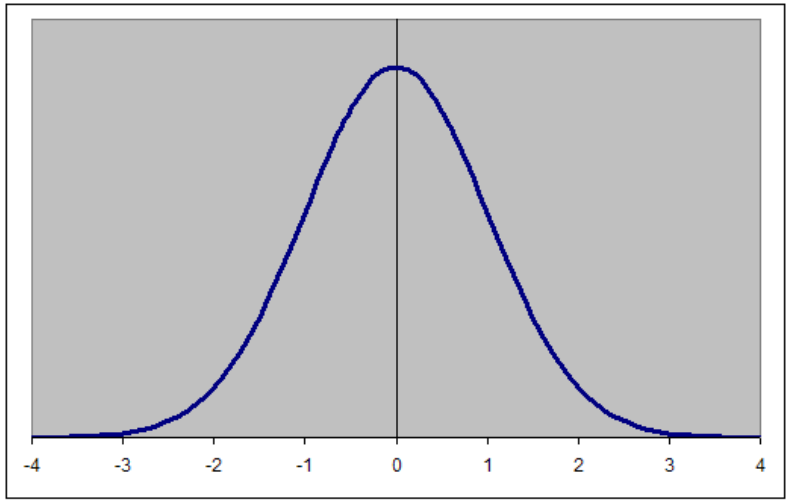
Statistical Regulatory Requirements (cont'd)

- **Results of Performance Assessments (40 CFR 194.34)**
  - **(b) "Probability distributions for uncertain disposal system parameter values used in performance assessments shall be developed and documented in any compliance application."**



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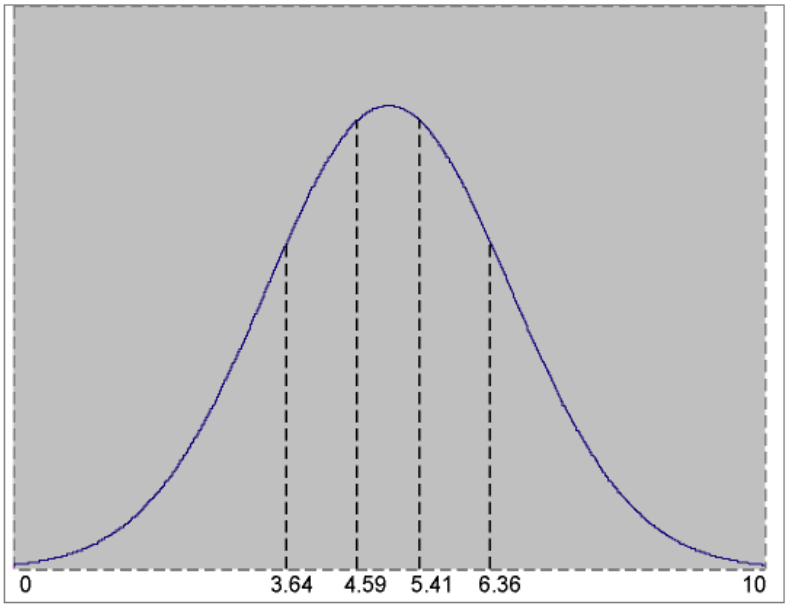
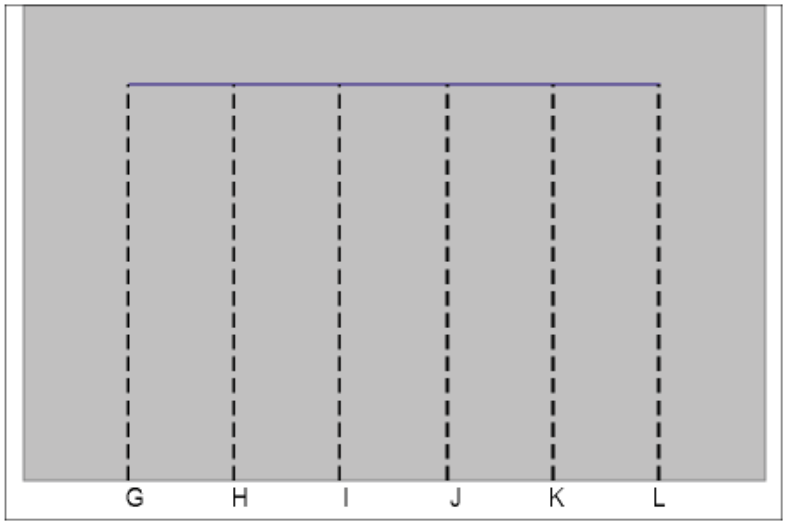
Statistical Regulatory Requirements (cont'd)

- **Results of Performance Assessments (40 CFR 194.34)**
  - **(c) "Computational techniques, which draw random samples from across the entire range of the probability distributions … shall be used in generating CCDFs and shall be documented in any compliance application."**
  - **WIPP PA uses Latin hypercube sampling**

Probability Density Functions

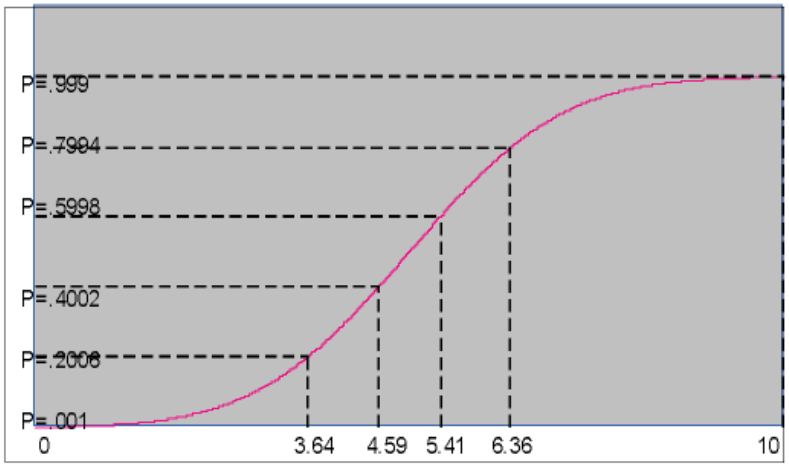


Normal Distribution

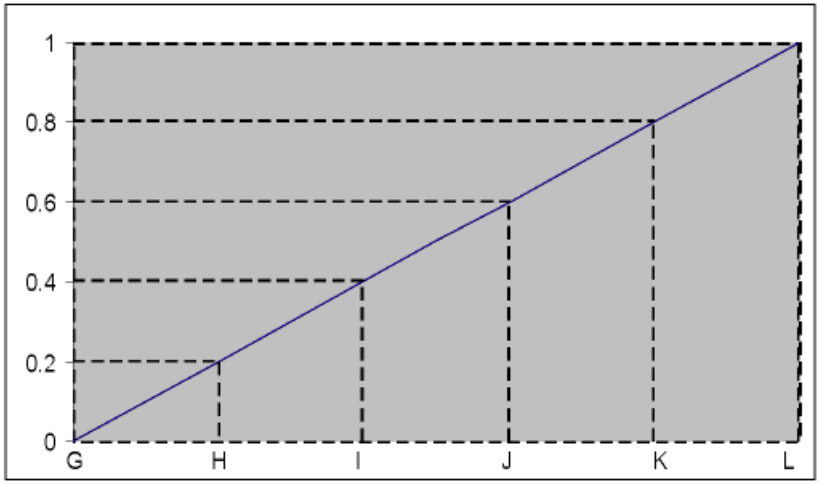


Uniform Distribution

Cumulative Distribution Functions



Normal Distribution



Uniform Distribution

Statistical Regulatory Requirements (cont'd)

- **Results of Performance Assessments (40 CFR 194.34)**
  - **(d) "The number of CCDFs generated shall be large enough such that, at cumulative releases of 1 and 10, the maximum CCDF generated exceeds the 99th percentile of the population of CCDFs with at least a 0.95 probability."**
  - **To determine the number of CCDFs required, one must solve the following inequality for n**

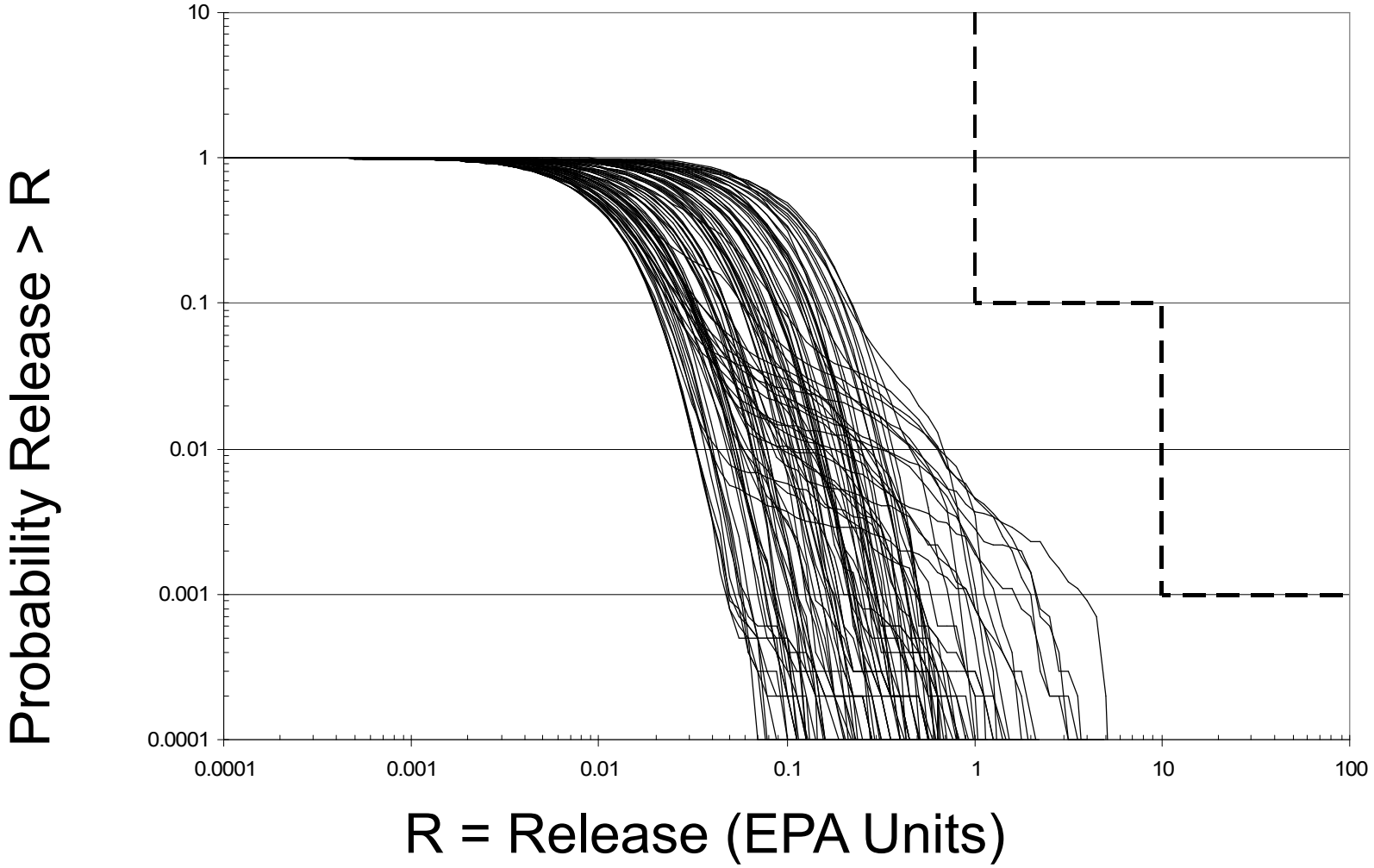
$$1-0.99^{n} > 0.95$$

  - **WIPP PA creates 300 CCDFs**

Statistical Regulatory Requirements (cont'd)

- **Results of Performance Assessments (40 CFR 194.34)**
  - **(e) "Any compliance application shall display the full range of CCDFs generated."**

Statistical Regulatory Requirements (cont'd)

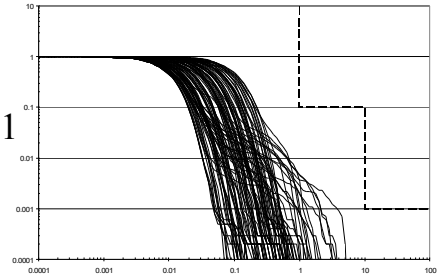


Statistical Regulatory Requirements (cont'd)

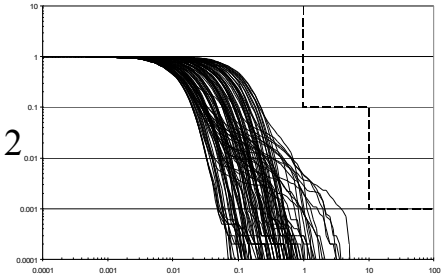
- **Results of Performance Assessments (40 CFR 194.34)**
  - **(f) Any compliance application shall provide information which demonstrates that there is at least a 95 percent level of statistical confidence that the mean of the population of CCDFs meets the containment requirements of Sec. 191.13 of this chapter.**

Statistical Regulatory Requirements (cont'd)

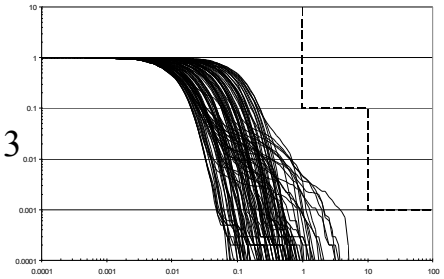
Replicate 1

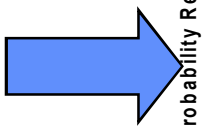


Replicate 2

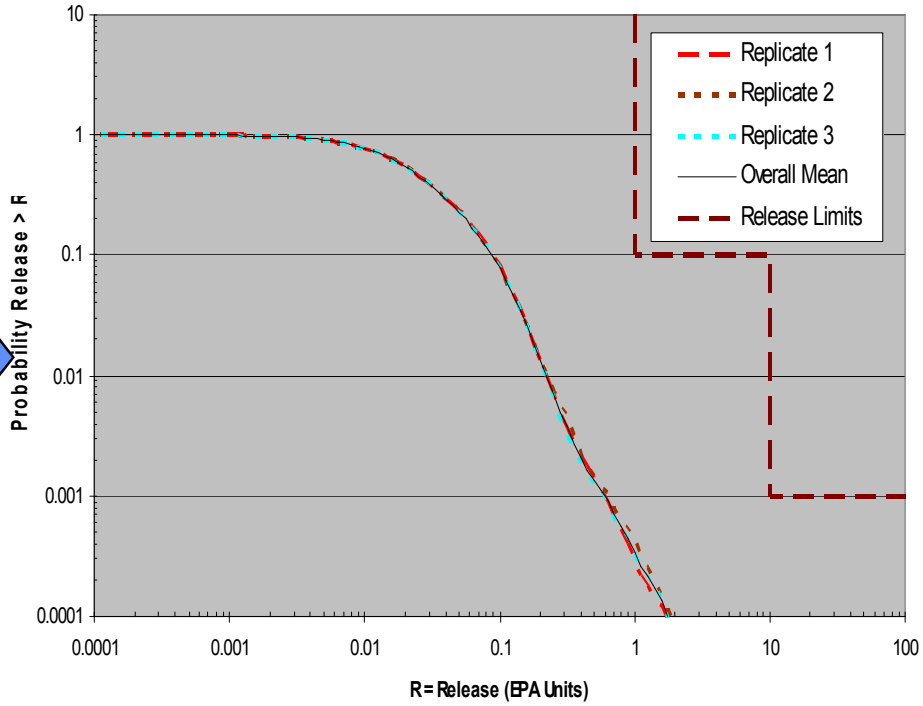


Replicate 3

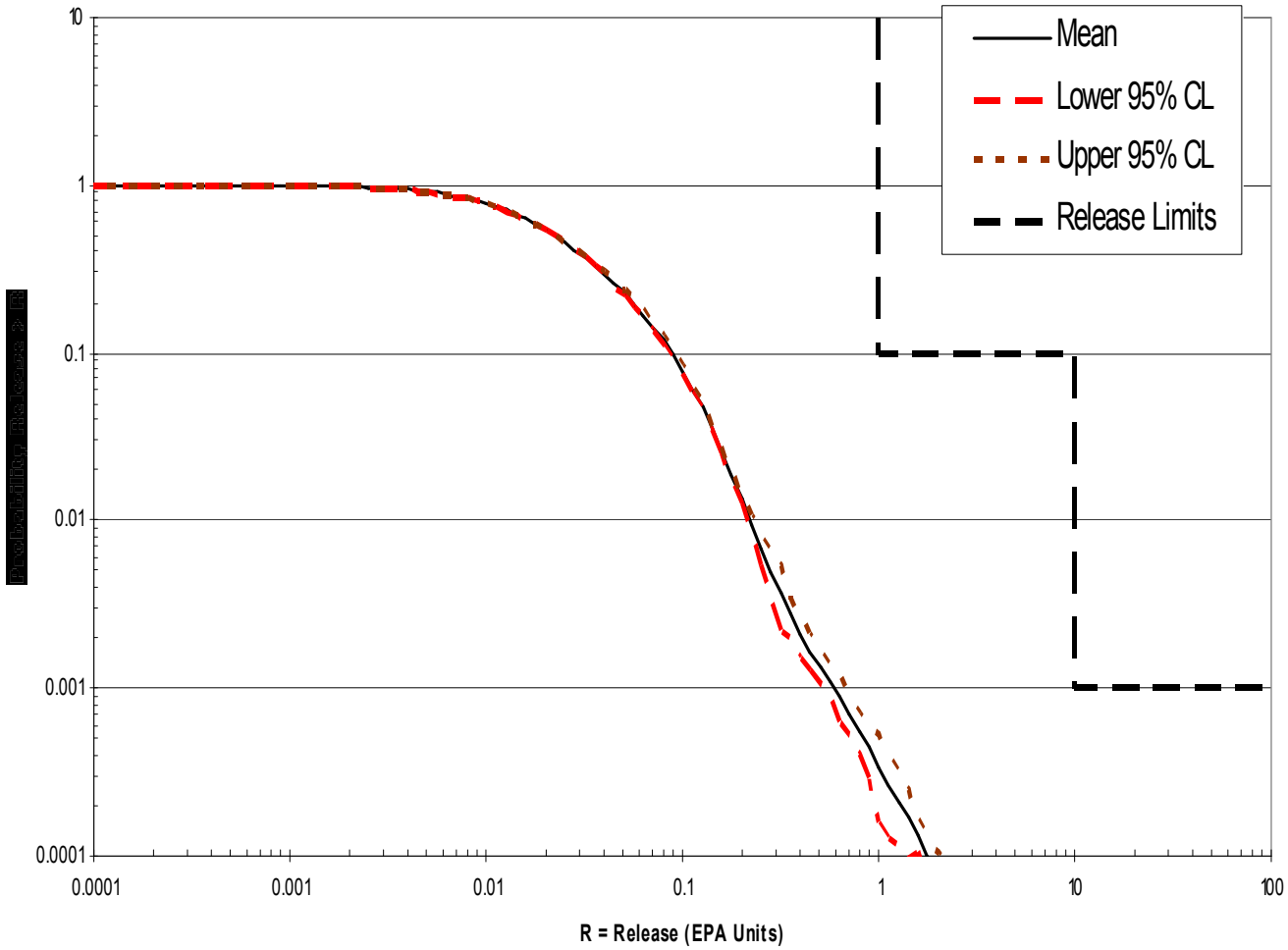




Mean CCDF for Each Replicate



Mean CCDF w/95% Confidence Intervals



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Statistical Regulatory Requirements (cont'd)

- Additional regulations dictate how assumptions about future uncertainties should be handled in WIPP PA.
  - These regulations will be discussed tomorrow (Dealing with Uncertainty)

Summary

- Calculation of releases differs for undisturbed and disturbed performance
- Disturbed performance is evaluated with normalized releases
- Normalized releases represent a fraction of the initial inventory that is released
- Release limits vary according to probability levels
  - Cumulative releases must remain less than 1 EPA Units (P=0.1)
  - Cumulative releases must remain less than 10 EPA Units (P=0.001)
- Regulations require that a probabilistic framework be used to demonstrate compliance with containment requirements