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U.S. Nuclear Regulatory Commission
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Subject: Programmatic Review of a Presentation for the 7th International Conference on Probabilistic Safety Assessment and Management (PSAM 7) in Berlin, Germany on June 14–18, 2004, titled "Sensitivity Analysis of an Engineered Barrier System Model for the Proposed Repository System in the United States"

Dear Mrs. DeMarco:

The enclosed presentation will be given at the 7th International Conference on Probabilistic Safety Assessment and Management (PSAM 7) in Berlin, Germany on June 14–18, 2004. The presentation is "Sensitivity Analysis of an Engineered Barrier System Model for the Proposed Repository System in the United States" by O. Pensado and B. Sagar. This presentation is based on a paper previously reviewed and approved by NRC in November 2003. The paper complements concepts discussed in a PSAM 6 paper by the same authors, and it presents results consistent with TPA 4.1 Sensitivity Analyses Report

The paper discusses a technique to perform sensitivity analyses of functions of time. The technique is applied to determine the main factors controlling the radionuclide release rate from the engineered barrier system.

Please contact me at (210) 522-5252 if you have any questions regarding these papers.

Sincerely yours,

Budhi Sagar
Technical Director

Enclosures

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Sensitivity Analysis of an Engineered Barrier System Model for the Potential Repository System in the US

Osvaldo Pensado and Budhi Sagar

Center for Nuclear Waste Regulatory Analyses

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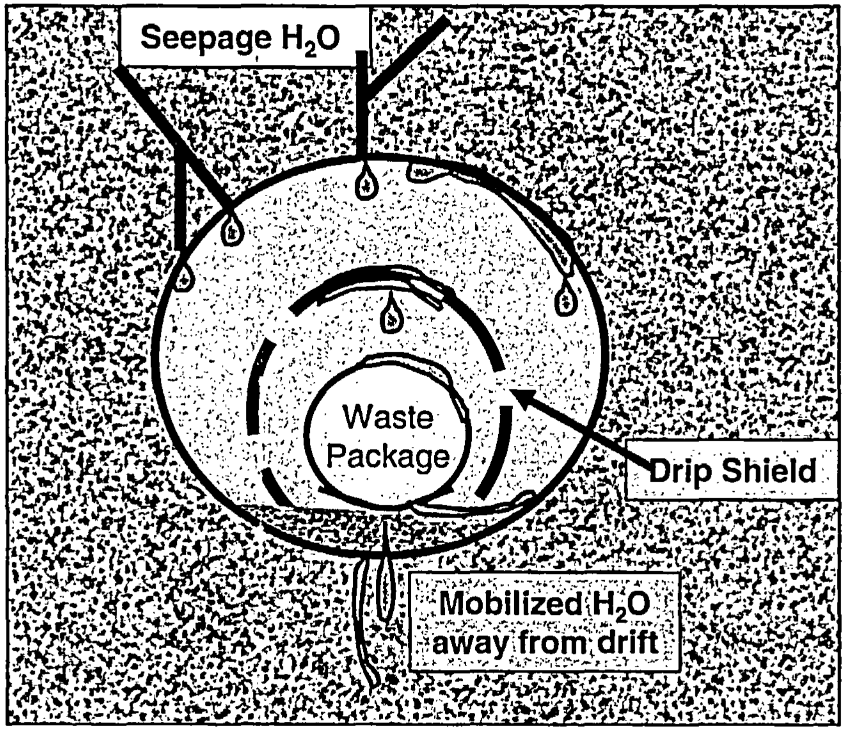
Introduction

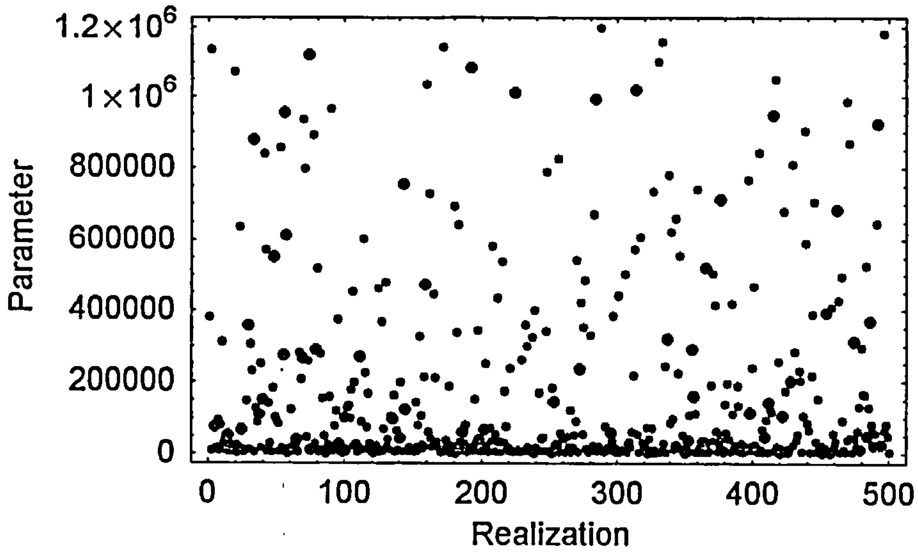
- Stochastic total system performance assessment code/model was developed in the US by the Nuclear Regulatory Commission to support evaluation of the potential geologic repository for spent nuclear fuel and high-level nuclear waste
- Sensitivity analyses support development of "risk-insights" about the potential geologic repository
- A technique is explored to identify influential parameters affecting outputs that are functions of time (e.g., total radionuclide release rate from the engineered barrier system)
- A novel method for sensitivity analyses, the partitioning method, is discussed

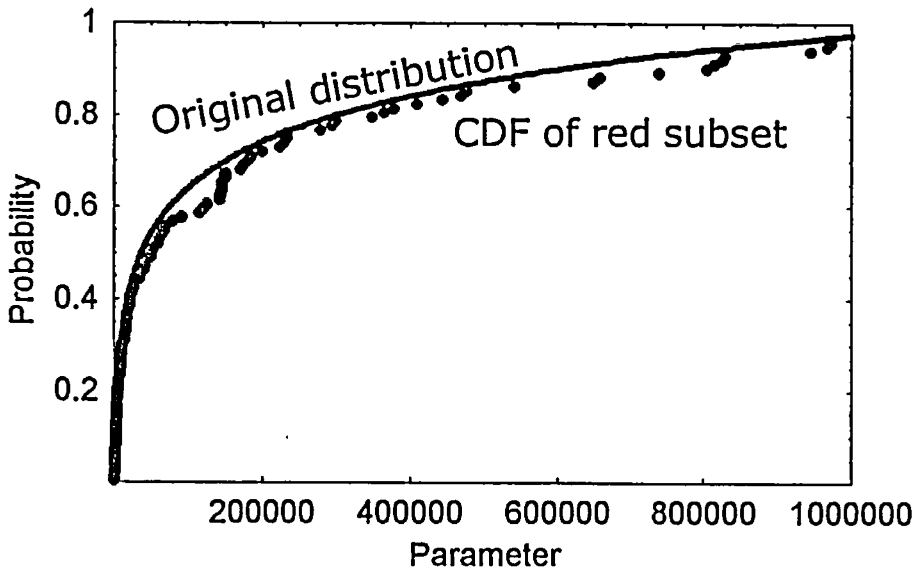
Engineered Barrier System Description



- The potential repository is to be located in the unsaturated zone
- Drip shield (DS) and waste package (WP) avoid or limit contact of nuclear waste with seepage water
- After failure of DS and WP, mobilized water away from drift could be contaminated with radionuclides
- Which factors control radionuclide release rates from the EBS?

Partitioning Method – 1

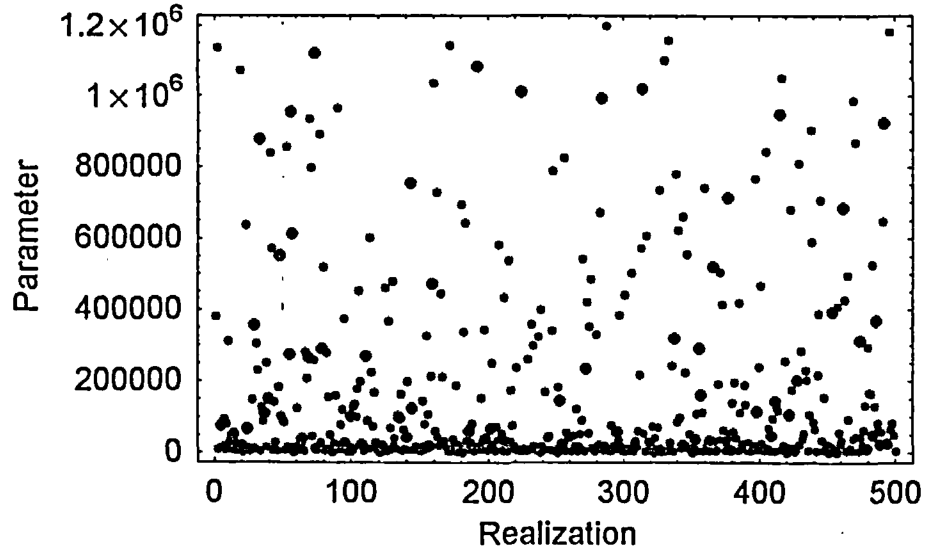


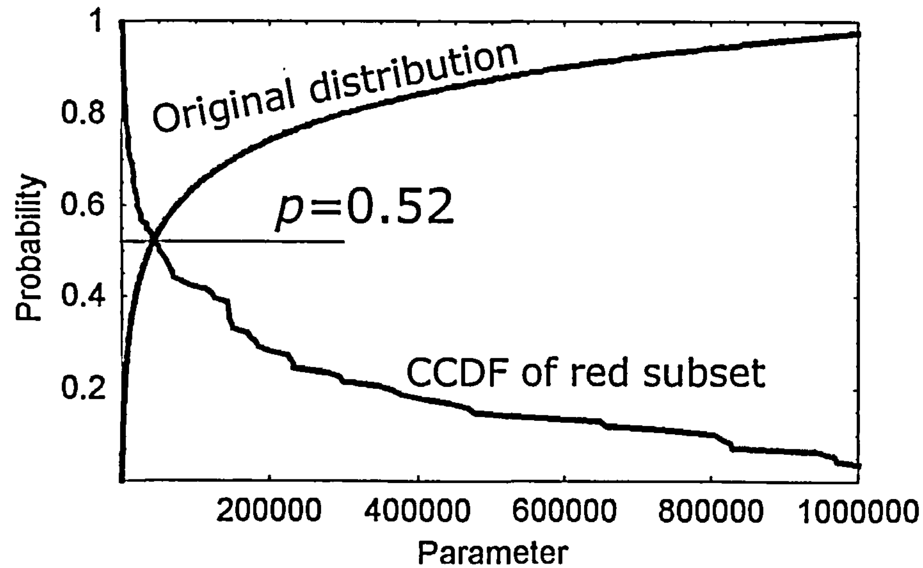


- Random selection of subset (red points) from original sample (black points) follows the original distribution

- Kolmogorov-Smirnov test can be used to measure deviation from original distribution

Partitioning Method – 2



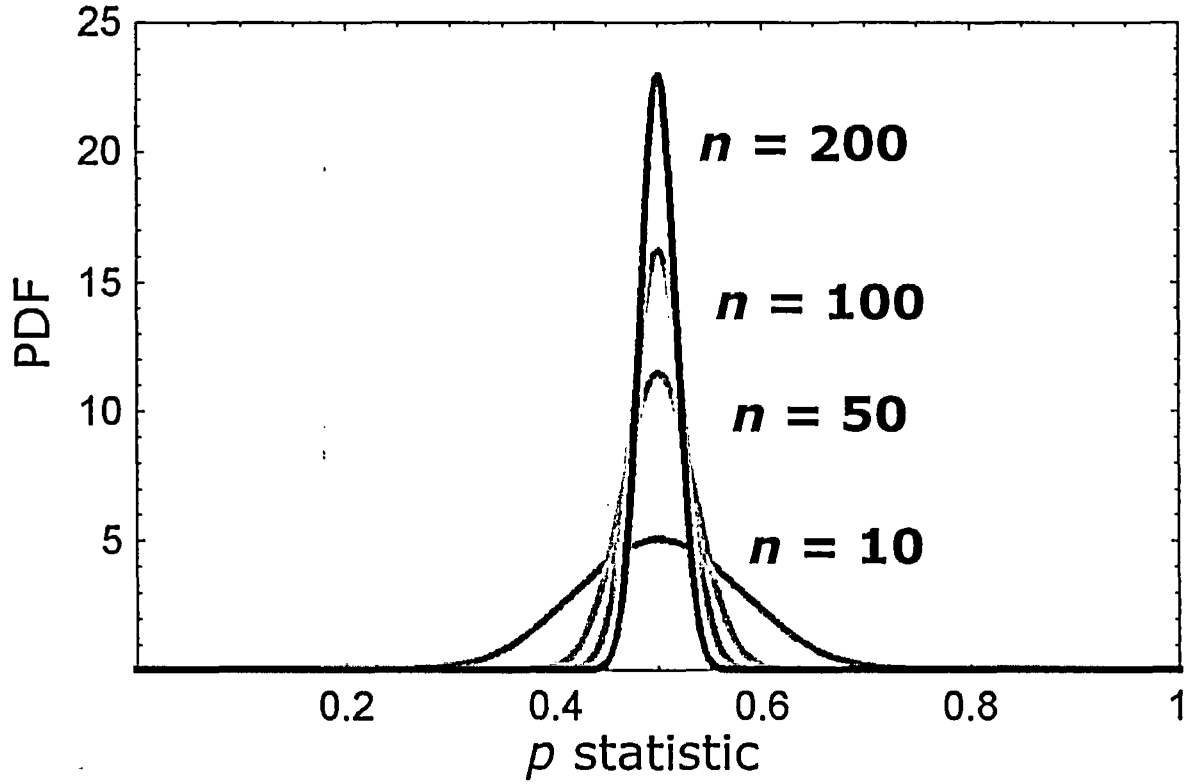


- Compare the full-set cumulative distribution function (CDF) to the subset complementary CDF
- Compute intersection of curves

p-statistics

- Mean: $\mu_p = 0.5$
- Std dev: $\sigma_p = 0.246\ n^{-0.5}$, n=subset population size
- p-distribution: beta distribution in [0, 1]
- p-distribution is independent of parameter set distribution

Partitioning Method – 3



_p_ distribution

Beta distribution in [0, 1]

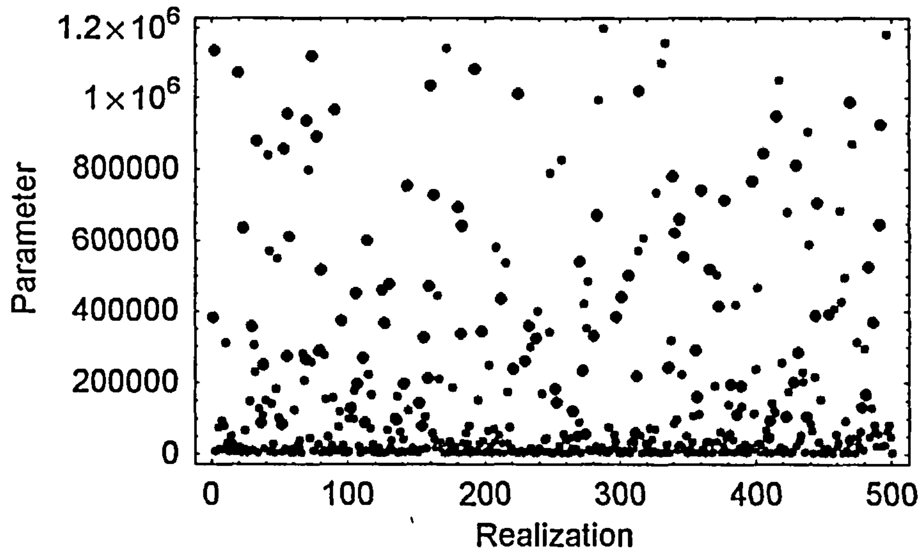
Shape parameters:

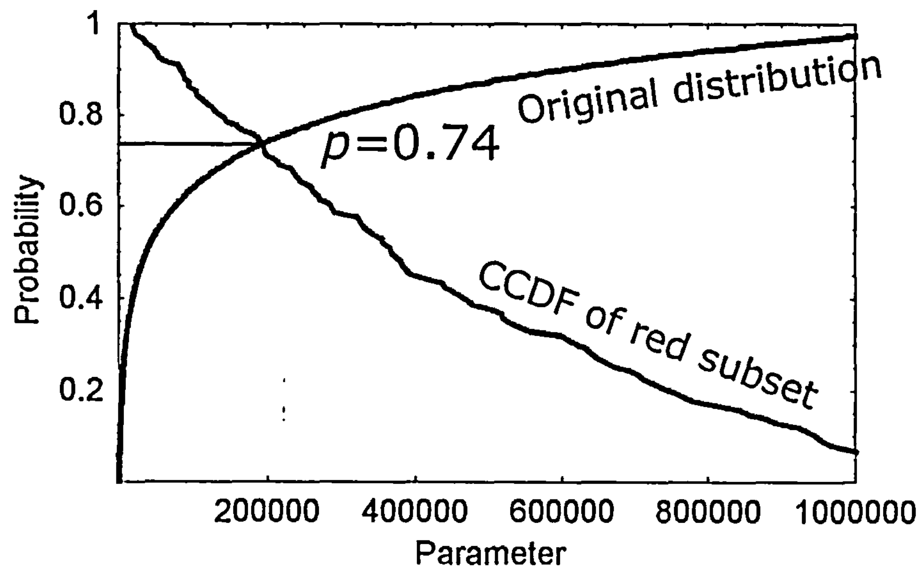
$\alpha = \beta = 1/(8\,\sigma_p^2) - 0.5$

$\sigma_p = 0.246\, n^{-0.5}$

n = subset population size

Partitioning Method – 4



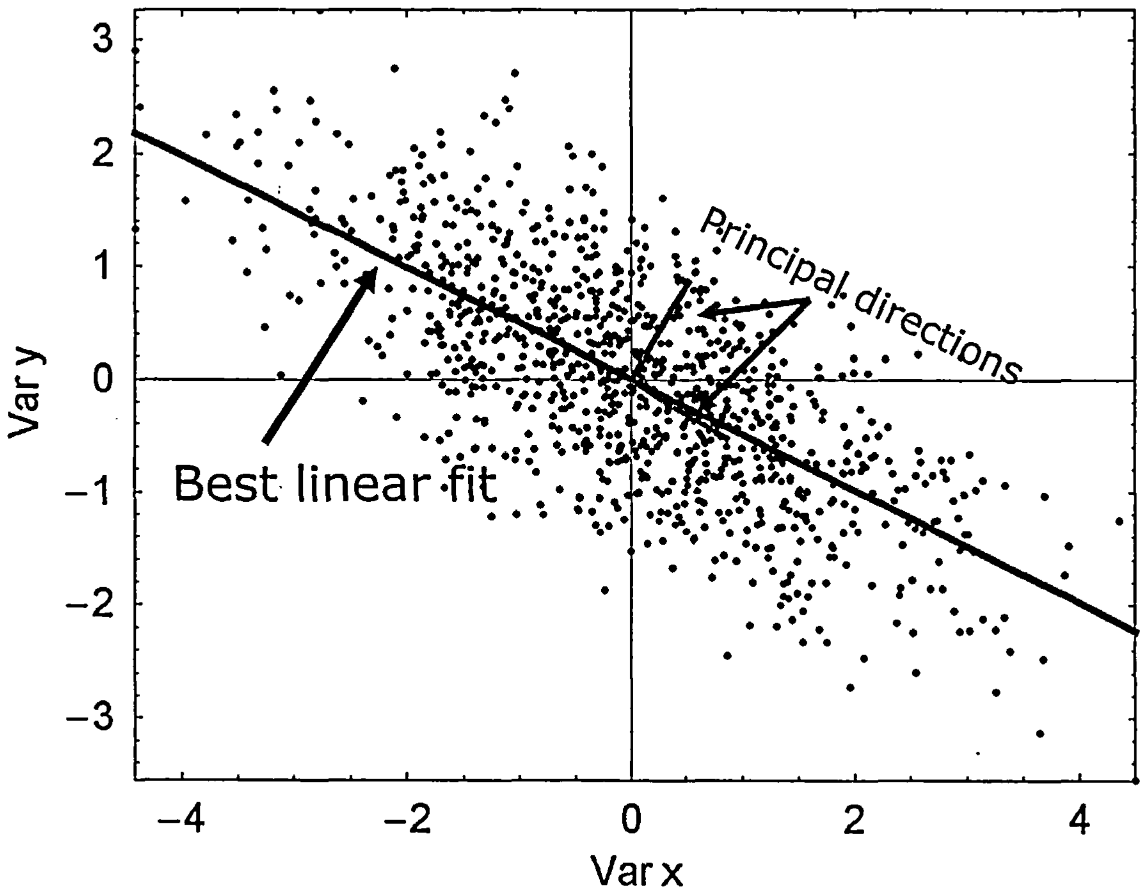


- Select subset based on a criterion
- Example: set of realizations with release rates above a mean value
- If $|p\text{-}0.5| > 99.9$ percentile of the (p-0.5) distribution then the performance metric is sensitive to the parameter
- **Sign(p-0.5)** : correlation sign between parameter and performance metric
  - $p - 0.5 > 0$: positive correlation
  - $p - 0.5 < 0$: negative correlation

Principal Component Decomposition – 1

- Technique proposed by M. McKay and K. Campbell to perform sensitivity analyses of stochastic outputs that are functions of time (PSAM6, 2002)
- We performed sensitivity analyses on principal components using the Partitioning Method

Principal Component Decomposition – 2



- x, y: stochastic variables
- Principal directions
  - orthogonal directions of maximum variation in x-y plane
  - indicated by eigenvectors of covariance matrix

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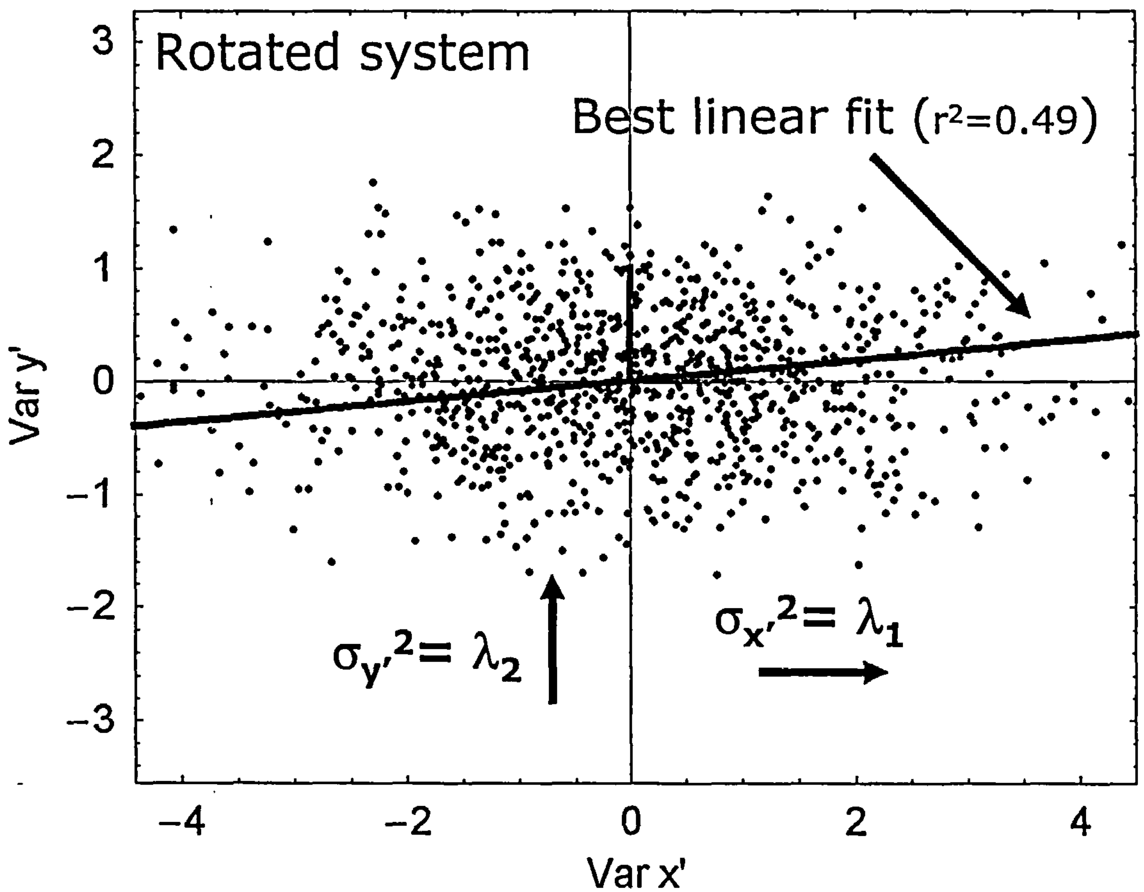
Principal Component Decomposition – 3



- Principal components: projections along principal directions (x' and y' coordinates)
- Variances along principal directions: eigenvalues (λ_1, λ_2) of covariance matrix

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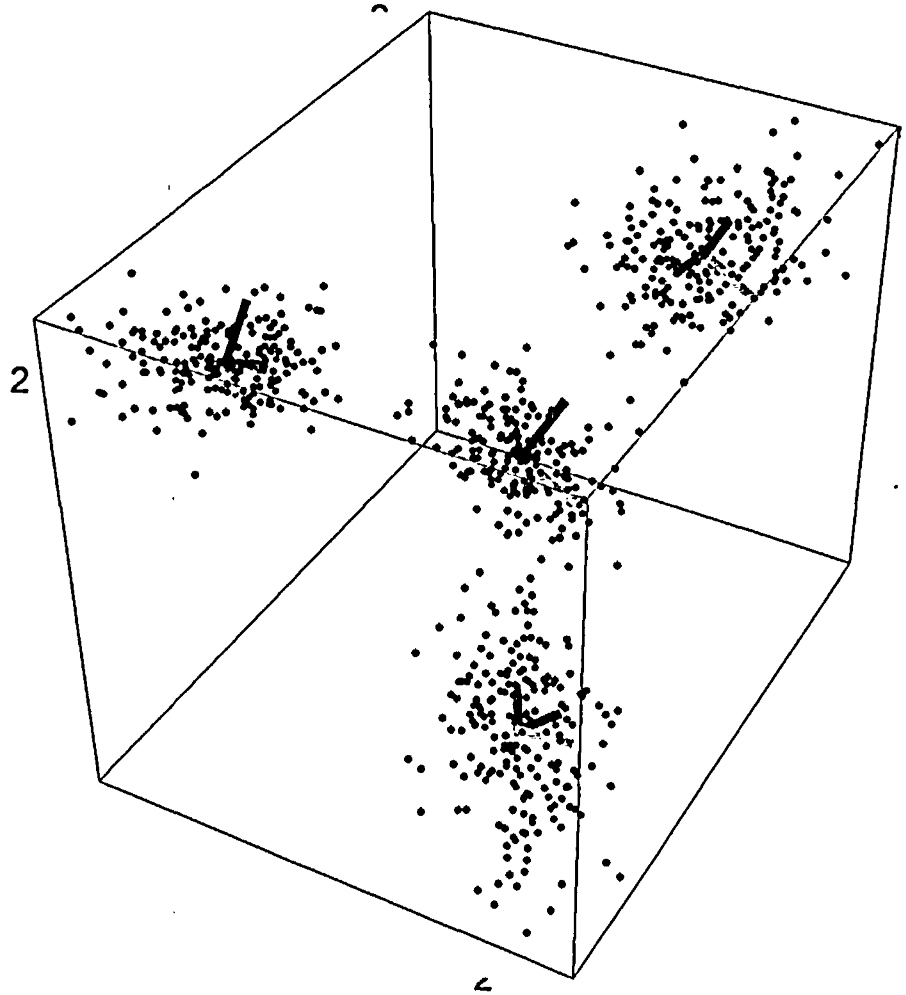
Principal Component Decomposition – 4



- In 3 dimensions, the principal directions are the axes of an ovoid

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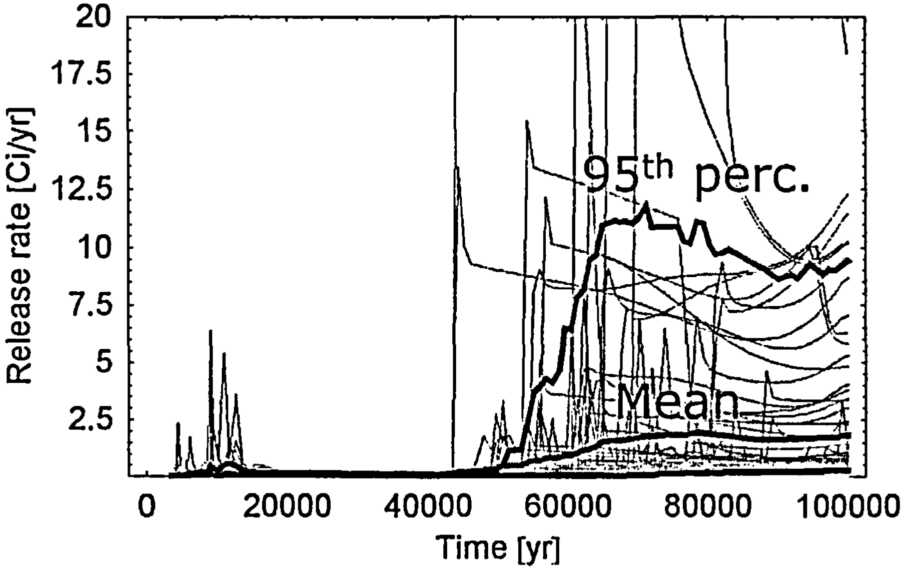
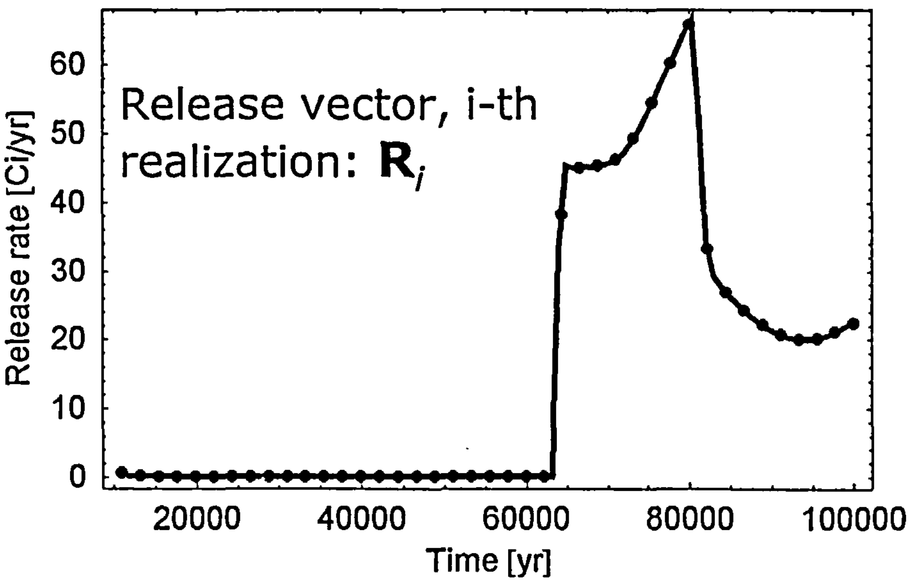
Sensitivity Analysis on EBS Release Rate as a Function of Time





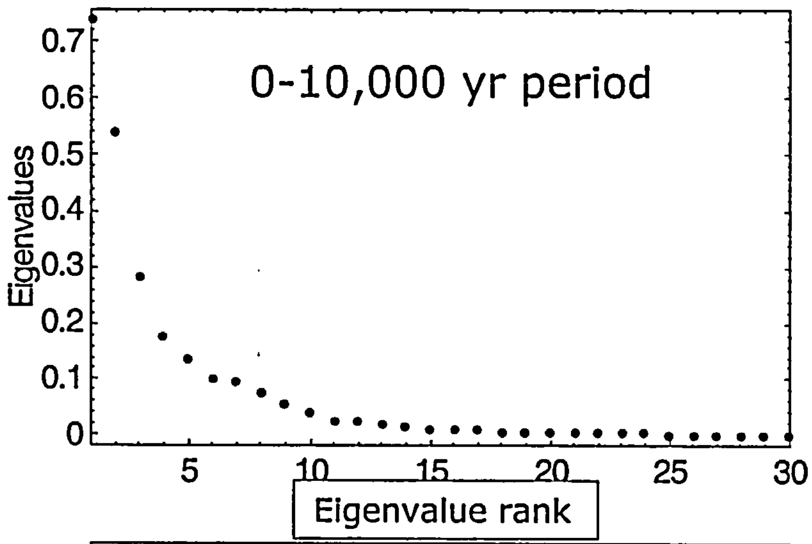
- Radionuclide release rates depend on spent fuel dissolution rates, solubilities, failure of EBS components, inventory, and seepage rates
- What are the dominant parameters? Can their influence be visualized?

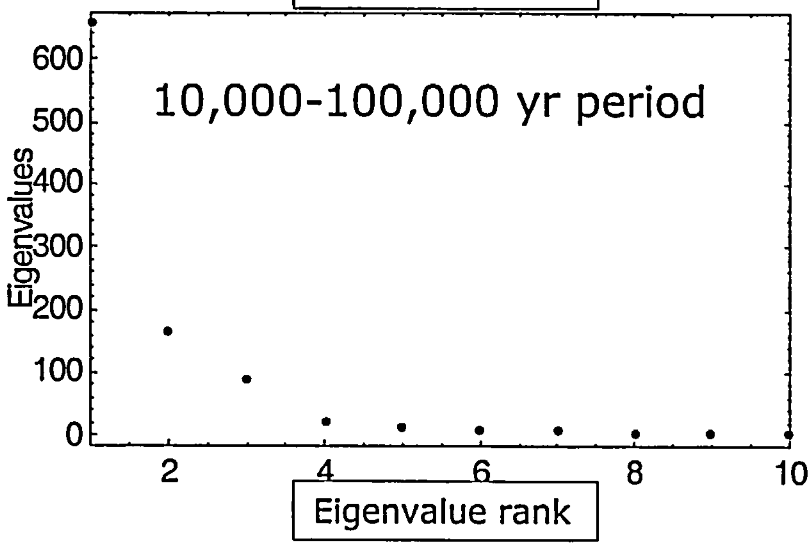
Sensitivity Analysis Technique

- Construct realization vectors by sampling particular timesteps (focused on two periods: 0–10,000[1] years and 10,000–100,000[2] years)
- Determine principal directions and principal components
- Perform sensitivity analysis on first few principal components using the partitioning method

(1) The regulatory period in the U.S. is 10,000 years.
(2) Analyses beyond 10,000 years can help elucidate the sensitivity of repository performance to processes or events occurring beyond the regulatory period.

Why Few Principal Components Suffice





- Square error of approximating $\mathbf{R}_i - \mathbf{R}_m$ as a linear combination of first k eigenvalues, averaged over all realizations, r, equals

$$\|\mathbf{e}_k\|^2 = \sum_{j=k+1}^{r} \lambda_j$$

Notation

- r : number of realizations
- $\mathbf{R}_i$: realization vector
- $\mathbf{R}_m$: mean release rate vector
- λ_j : eigenvalue
- $\|\mathbf{e}_k\|^2$: square error

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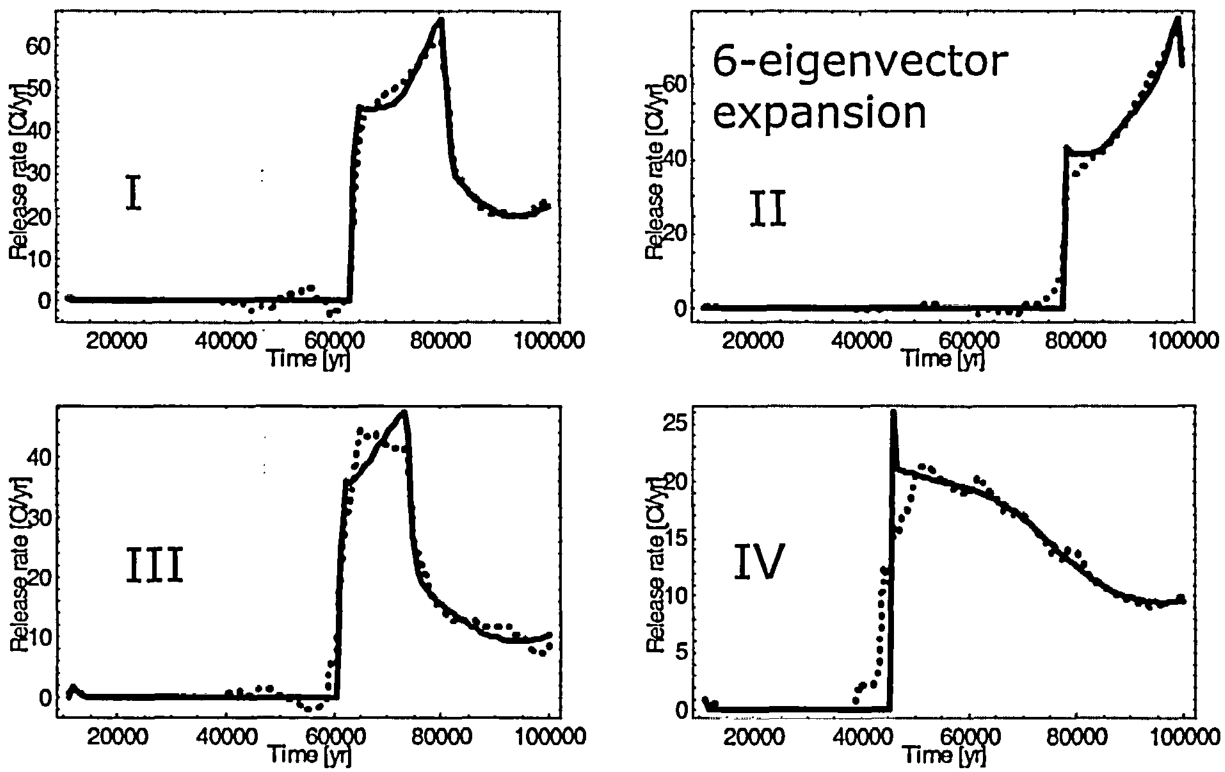
Eigenvector Expansion Approximation; Realizations With Highest Releases



- First principal component: magnitude of release rate (spent fuel dissolution rate)
- Second and third principal components: timing of release (corrosion rate) and magnitude
- Higher order principal components: details in release rate curve

Results

- Partitioning method applied on principal components
- Discriminating set: realizations with positive (or negative) principal component (sum of principal components equals zero)
- Candidate influential parameters identified using the 99.9 percentile of the distribution of the *p*-0.5 statistic
- Ranking established by counting frequency a parameter was identified as influential in first 10 principal components

0 – 10,000 years

- SF Dissolution Rate (pre-exponential factor)
- Waste Package Flow Multiplication Factor
- Drip Shield Failure Time
- Subarea Wet Fraction
- Starting Areal Average Mean Annual Infiltration
- Fraction Of Condensate Removed (reflux process)
- Initial Defective Fraction Of WPs

10,000 – 100,000 years

- SF Dissolution Rate (pre-exponential factor)
- Alloy 22 General Corrosion Rate
- Subarea Wet Fraction
- Starting Areal Average Mean Annual Infiltration

Conclusions

- The partitioning method (PM) was developed as a sensitivity analysis technique.
- Radionuclide release rate from the engineered barrier system (EBS) was studied using the PM combined with the principal component (PC) decomposition to perform sensitivity analyses on functions of time:
- Influential parameters were identified and ranked
  - 0 ÷ 10,000 years : spent fuel dissolution rate, parameters controlling seepage rates at the drift and failure time of the drip shield
  - 10,000 – 100,000 years : spent fuel dissolution rate, general corrosion rate of waste package materials, and parameters controlling seepage rates at the drift
- The identified influential parameters are consistent with those determined using other sensitivity techniques (e.g., Mohanty and Wu, PSAM6, 2002). The present technique does not require definition of point-performance metrics.

Acknowledgements

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- This paper is an independent product of the CNWRA and does not necessarily reflect the view or regulatory position of the NRC.