Global Sensitivity Analyses Methods for Generating Risk Information

Presented by
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Presentation Outline

- Background
- Review of Three Sensitivity Analysis Methods
- Results
- Verification
- Summary and Conclusions

Background

- Quantitatively investigate the applicability of methods for conducting uncertainty and sensitivity analyses to identify influential aspects affecting output of a complex numerical model

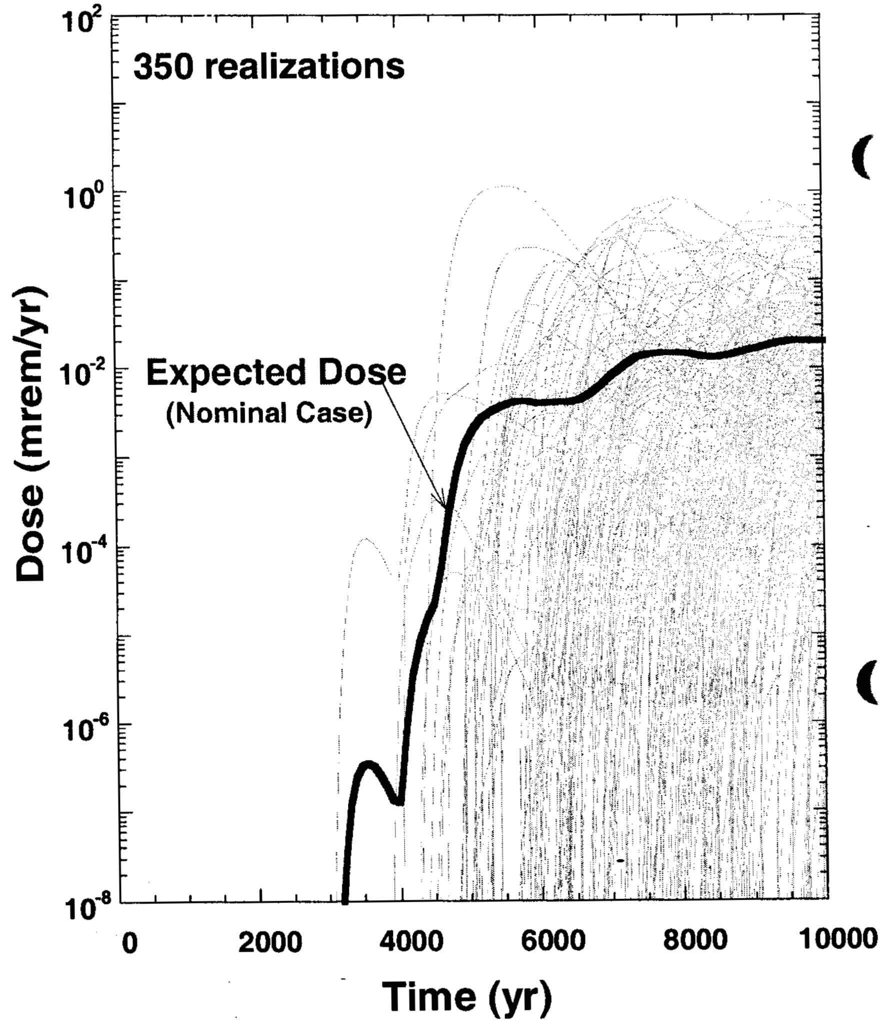
- Focus analysis efforts on most significant aspects such as components, processes, events, and parameters

Background (cont'd)

- Sensitivity analysis is used as one of the tools for risk-informing regulatory reviews
- "Importance" is nonuniquely defined— select of sensitivity measure to fit specific objective
- NRC regulation requires that the mean dose in 10,000 year not exceed 0.15 mSv/yr
- Need to rank influential aspects by their sensitivity to peak mean dose

Application Problem

- A probabilistic computer model (TPA code) for estimating performance of the potential high-level waste repository at Yucca Mountain, Nevada
- Types of uncertainty: data (quantified via PDFs), models, system scenarios, and systematic factors (e.g., QA, institutional bias)
- Model has 965 parameters: 330 currently sampled, 43 correlated



Parameter Tree Approach

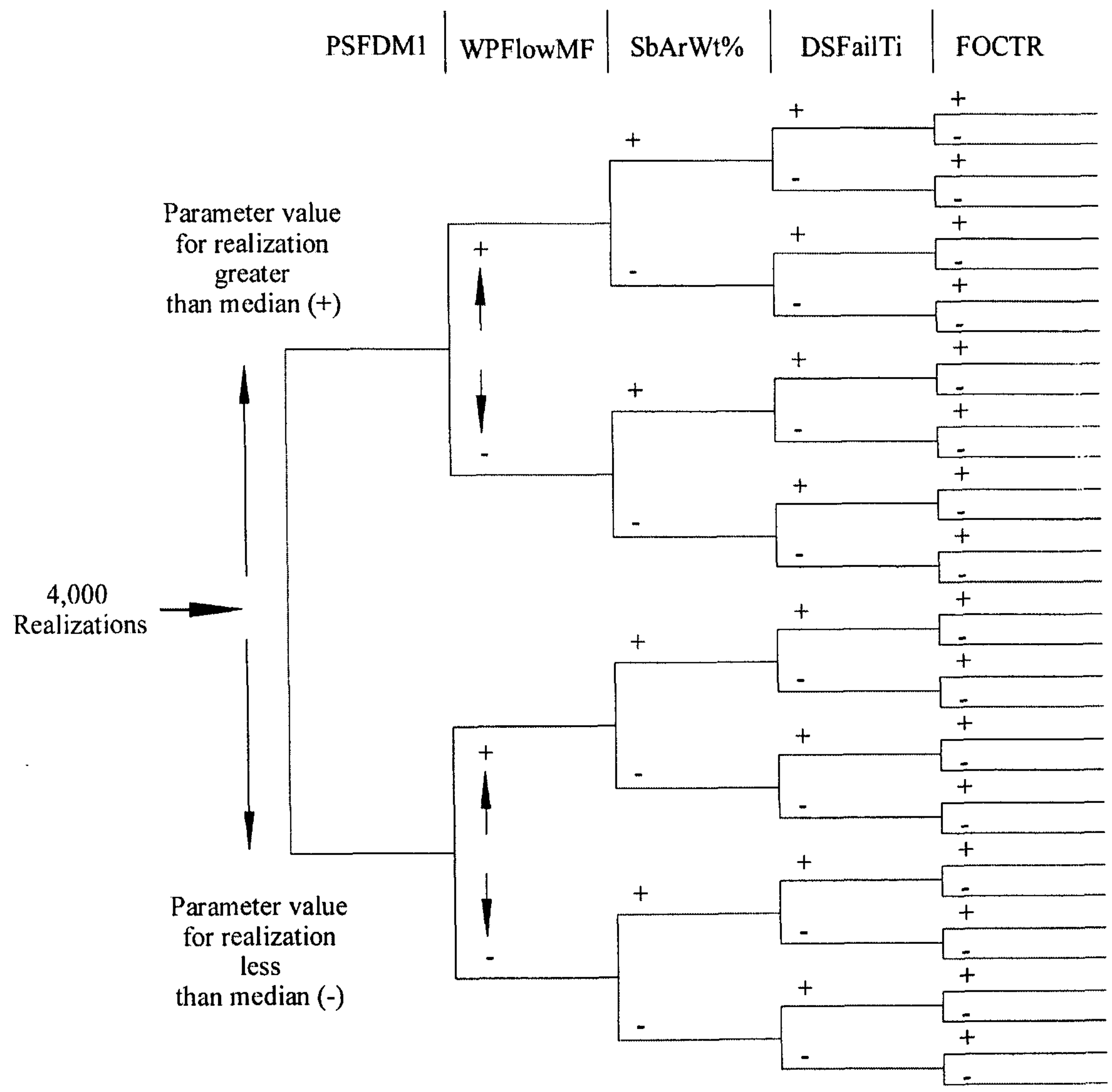
- Classify (bin) input parameter values as above or below a branching criterion (e.g., mean, median, *x* percentile)
- Aggregate corresponding model output into similar bins
- Construct a multiple-level-branch tree combining various parameters (each level represents a parameter)

$$\text{Sensitivity} = \frac{\text{Number of realizations with high (low) dose associated with a branch}}{\text{Number of realizations with high (low) parameter values associated with the same branch}}$$

- Advantages:
  - Does not require pre-selection of parameter values as in the "design-of-experiment" technique
  - Can be used to evaluate a set of parameters, rather than one parameter at a time
- Disadvantage:Number of simulations needed is large if large sets of parameters are investigated

Parameter Tree Approach (cont'd)

[Jarzemba and Sagar, 2000, RESS]



A	B	C	D
70 /122	1.80E-04	0.1037	3.40
55/131	7.16E-05	0.0443	1.35
123/127	5.57E-04	0.3340	10.52
98/129	2.50E-04	0.1524	4.72
59 /124	3.24E-05	0.0190	0.61
37/114	2.90E-05	0.0156	0.55
120/130	1.18E-04	0.0727	2.24
75/125	4.51E-05	0.0266	0.85
45/114	1.41E-05	0.0076	0.27
34/135	1.14E-05	0.0073	0.22
110/124	1.06E-04	0.0618	1.99
76/121	3.99E-05	0.0228	0.75
31/126	4.46E-06	0.0026	0.08
26/132	1.96E-06	0.0012	0.04
88/128	2.25E-05	0.0136	0.43
48/118	5.63E-06	0.0031	0.11
62/122	1.38E-05	0.0079	0.26
41/133	8.41E-06	0.0053	0.16
117/123	4.98E-05	0.0289	0.94
105/133	5.01E-05	0.0314	0.95
49/119	4.21E-06	0.0024	0.08
34/113	9.93E-06	0.0053	0.19
118/132	2.02E-05	0.0126	0.38
66/123	1.03E-05	0.0060	0.19
29/134	1.96E-06	0.0012	0.04
14/110	3.61E-07	0.0002	0.01
94/122	9.67E-06	0.0056	0.18
58/120	4.71E-06	0.0027	0.09
19/138	2.09E-07	0.0001	0.00
13/133	4.99E-07	0.0003	0.01
46/115	1.50E-06	0.0008	0.03
40/130	1.70E-06	0.0010	0.03

Mean Response-Based Method

- Two mean-based sensitivity measures:

$$\partial \mu_Y / \partial \mu_{X_i}$$

$$\partial \mu_Y / \partial \sigma_{X_i}$$

- Acceptance limits

$$P\left[-Z_{\alpha/2} \le \frac{\overline{S}_{Y_\mu} - S_{Y_\mu}}{\sqrt{E\left[Y^2\right]/k}} \le Z_{\alpha/2} \right] \le 1-\alpha$$

$$P\left[-Z_{\alpha/2} \le \frac{\overline{S}_{Y_\sigma} - S_{Y_\sigma}}{\sqrt{2 \cdot E\left[Y^2\right]/k}} \le Z_{\alpha/2} \right] \le 1-\alpha$$

$$S_{Y_\mu} = \frac{\partial \mu_Y}{\partial \mu_{Z_i}} = \int_{All\ u} Y(\boldsymbol{u}) \frac{\partial \phi(\boldsymbol{u}, \mu_Z, \sigma_Z)}{\partial \mu_{Z_i}} d\boldsymbol{u} = E\left[u_i Y(\boldsymbol{u})\right]$$

$$\overline{S}_{Y_\mu} = \frac{1}{k} \sum_{j=1}^{k} \left[u_i Y\right]_j$$

$$S_{Y_\sigma} = \frac{\partial \mu_Y}{\partial \sigma_{Z_i}} = \int Y(\boldsymbol{u}) \frac{\partial \phi(\boldsymbol{u}, \mu_Z, \sigma_Z)}{\partial \sigma_{Z_i}} d\boldsymbol{u} = E\left[(u_i^2 - 1) Y(\boldsymbol{u})\right]$$

$$\overline{S}_{Y_\sigma} = \frac{1}{k} \sum_{j=1}^{k} \left[(u_i^2 - 1) Y\right]_j$$

μ_Y = Peak Mean Dose

μ_{X_i} = Mean of parameter X_i

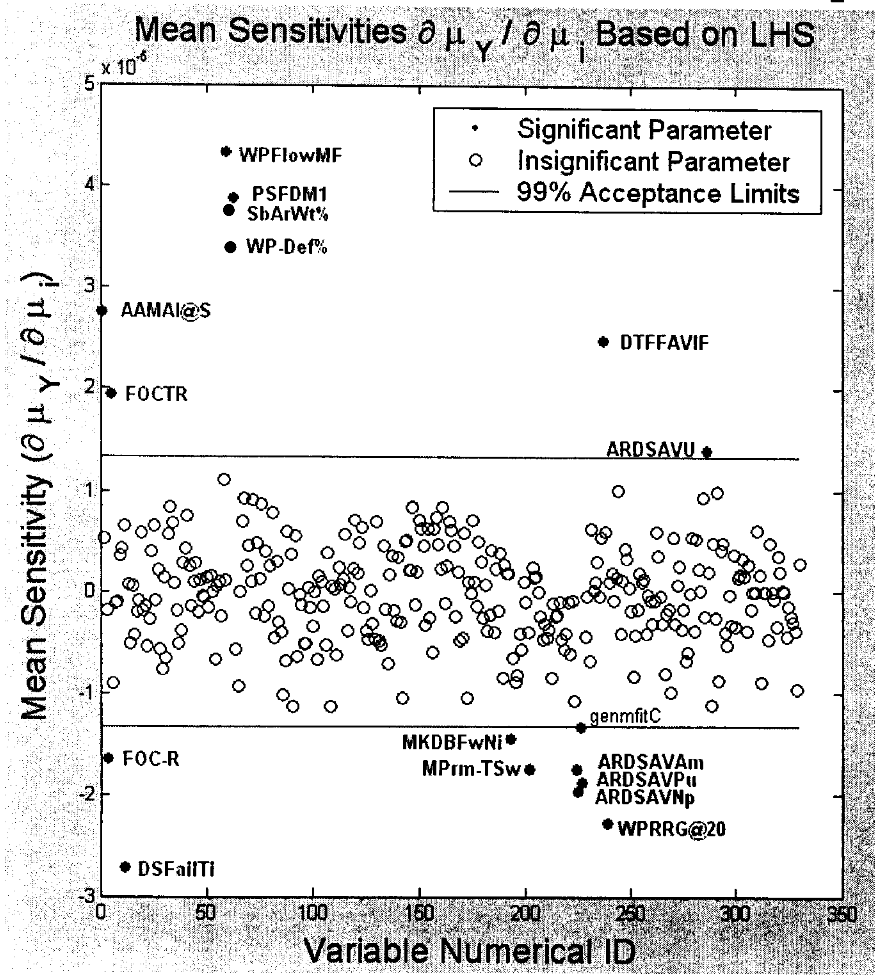
σ_{X_i} = Standard Deviation of X_i

z_i = Transformed (normalized) X_i

Y = Response variable (i.e., output)

Mean Response-Based Method (cont'd)

[Mohanty and Wu, 2002, PSAM6]

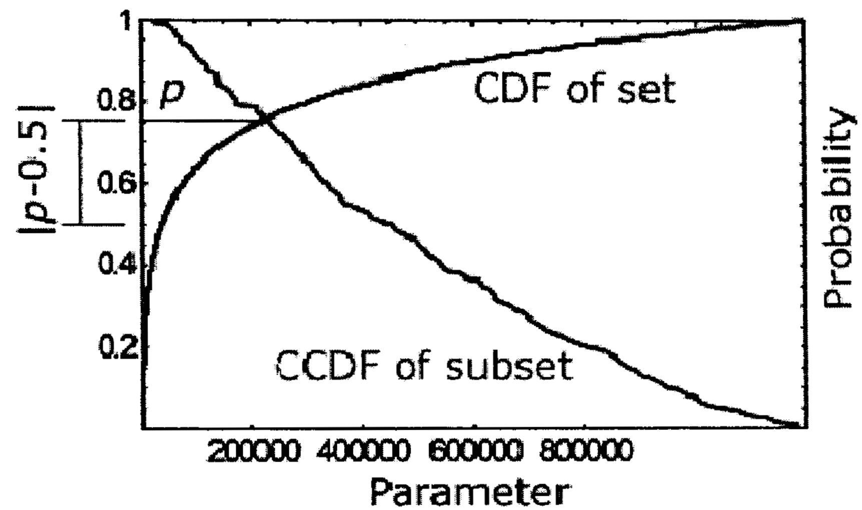


- Advantages:
  - Sensitivities are particularly relevant to the U.S. HLW regulatory criteria
  - Transparently shows the influential parameters at a user-specified acceptance limit
  - Transparently shows the number of realizations needed to obtain stable results
- Disadvantage:
  - Minimum number of realizations needed for stable results is a strong function of the rate of model output convergence to a stable mean

Partitioning Method

- Partition realizations into two sets w.r.t an output threshold
- Select for each parameter the set with fewest realizations
- Compute complementary CDF (CCDF)
- Compare subset CCDF with the population CDF
- $|p-0.5|$ is a measure of the parameter's influence on output

[Pensado, Sagar, Wittmeyer, 2002, PSAM6]

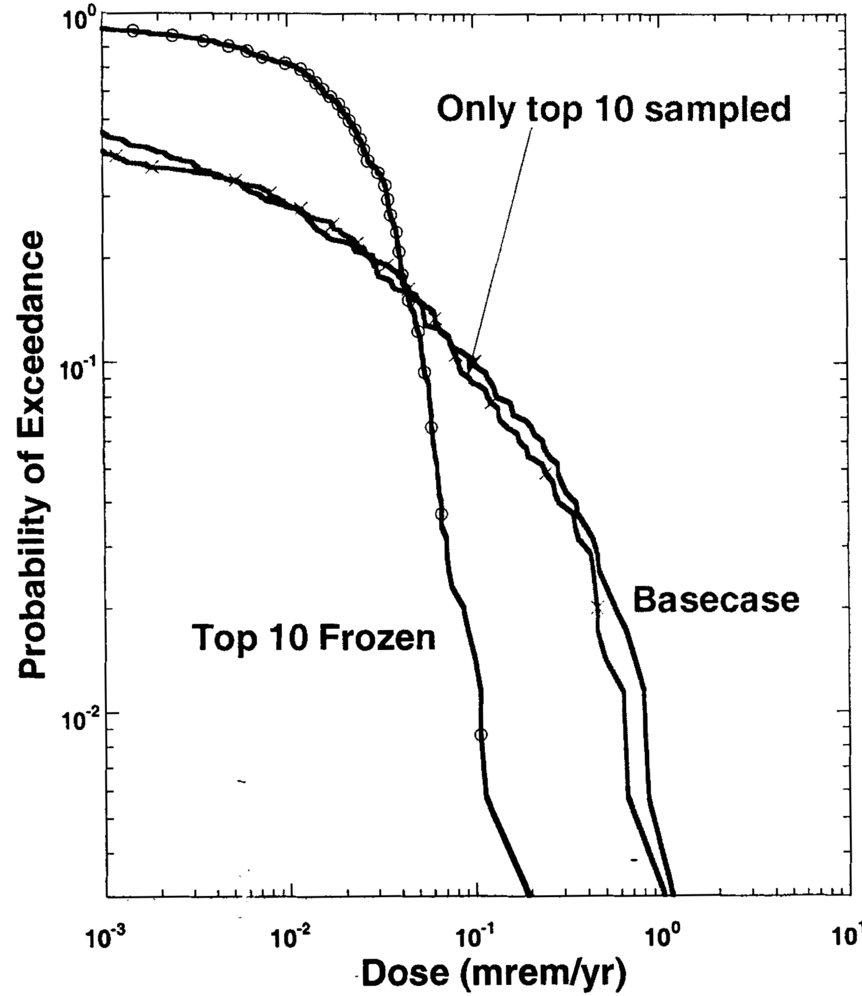


Partitioning Method (cont'd)

- Parameters selected if $|p\text{-}0.5|>2\times0.246 \times n^{-1/2}$ (n is the size of the characteristic set)
- Advantages:
  - Simple method
  - High sensitivity to correlation signs
- Disadvantage:
  - Correlation sign meaningful only if known that there is a monotonic relationship between input and output

Comparison of the Three Methods

Rank	Parameter Tree	CDF Mean-based Sensitivity	Partitioning Method
1	PSFDM1	WPFlowMF	PSFDM1
2	WPFlowMF	PSFDM1	WPFlowMF
3	SbArWt%	SbArWt%	SbArWt%
4	DSFailTi	WP-Def%	DSFailTi
5	FOCTR	AAMAI@S	AAMAI@S
6	*Chlorid	DSFailTi	WP-Def%
7	Solbl-Np	DTFFAVIF	FOC-R
8	Gen-hirP	WPRRG@20	FOCTR
9	-	ARDSAVNp	MPrm_TSw
10	AAMAI@S	FOCTR	WPRRG@20



Summary

- Three CNWRA-developed different sensitivity analysis methods explored
- Calculations show that uncertainties in the top 10 influential parameters out of 330 account for most performance uncertainty
- Sensitivity analyses indicate focus for the TPA code model improvement
  - Factors controlling spent fuel dissolution show substantial uncertainties
  - Factors controlling water/fuel contact dominate performance
  - Most dose from low-retardation and long-lived radionuclides
- Sensitivity analysis helps NRC/CNWRA risk-inform the review of DOE post-closure analyses during the pre-licensing interactions

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