Risk Assessment in the Disposal of High-level Radioactive Waste

Sitakanta Mohanty
Center for Nuclear Waste Regulatory Analyses
San Antonio, Texas, USA
smohanty@swri.org

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Outline

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Purpose

- Outline a risk assessment methodology applicable to the disposal of high-level nuclear waste (developed for the regulator)

Background

- A thorough risk assessment of any proposed high-level waste repository is essential because high-level waste is extremely hazardous

- Risk assessment of HLW disposal systems is unique because
  - The system is complex; a mixture of engineered and natural components
  - Limited prior experience with such a system world wide
  - Long time period for which assessments are needed
  - Designs and host geology differ from one repository to another (i.e., risk assessment highly repository-specific)
  - Public sensitivity to all aspects of the nuclear fuel cycle is very high

Background (cont'd)

- Probabilistic risk assessment (PRA) for the power plant cannot be readily adapted to the repository problem:
  - Failures gradually evolve as a function of time -- not ON-OFF type
  - Consequences usually evolve slowly, typically not catastrophic such as a core melt

- In the waste disposal arena, long-term risk assessment is referred to as "performance assessment"
- PRA applies only to the pre-closure period (a short duration compared to the regulatory compliance period)

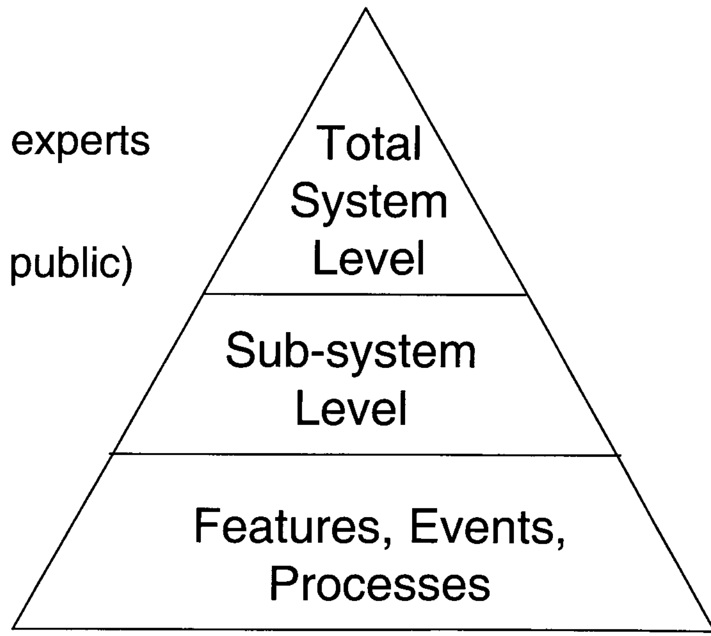
Background (Cont'd)

- Risk-Informed Performance-based approach to decision making
  - Regulations in many areas rapidly becoming risk-informed and performance-based
  - Quantitative risk assessment becoming the foundation for regulatory acceptance

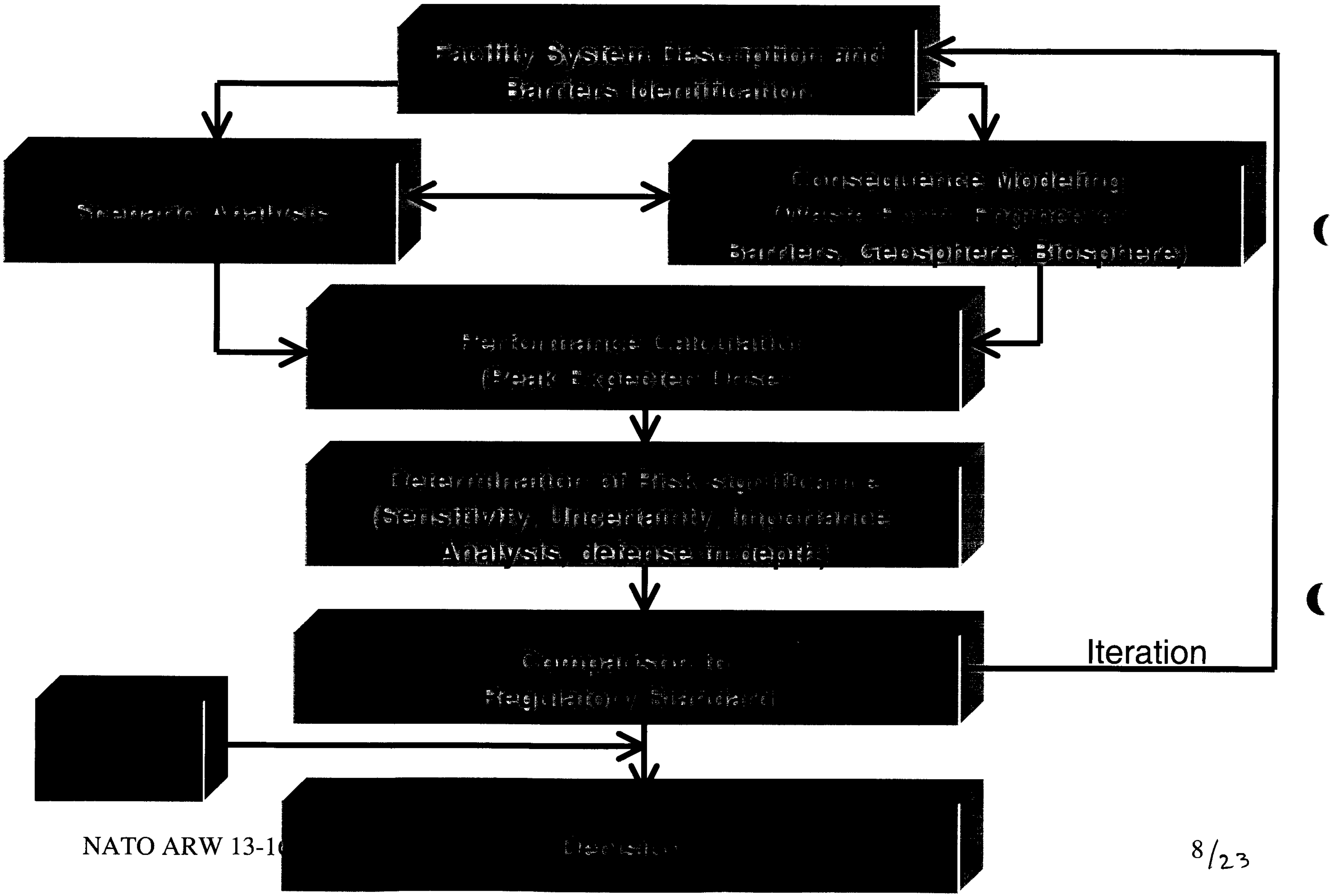
Risk-based	Regulatory decisions made solely based on the numerical results of a risk assessment
Risk-informed	Risk insights considered together with other factors
Performance-based	Performance and results are basis for the regulatory decision making (measurable parameters to monitor performance, objective criteria for monitoring; flexibility to determine method to meet performance goals)
Prescriptive	Regulation provides detailed process, requirements, or instructions to follow; A conservative approach; used in the absence of an effective methodology to deal with uncertainty
Risk-informed performance based	Risk insights, engineering analyses, and judgments including principles of defense in depth, safety margin incorporation, and performance history used; actions based on monitoring of performance

Performance Assessment

- Performance assessment is a formal and systematic process by which the safety of a repository after it is permanently closed is quantified
- Why conduct performance assessment?
  - Investigate the influence of scenarios, conceptual models, parameters
  - Identify factors most important to system safety (i.e., vulnerabilities that need further study
  - Aid communication between
    - risk analysts and process-level subject matter experts
    - technical staff and management
    - management staff and the stakeholders (e.g., public)
- Key elements of performance assessment
  - Scenario analysis
  - Abstracted model development
  - Model integration
  - System-level analysis
  - Defense-in-depth analysis



Total System Performance Assessment



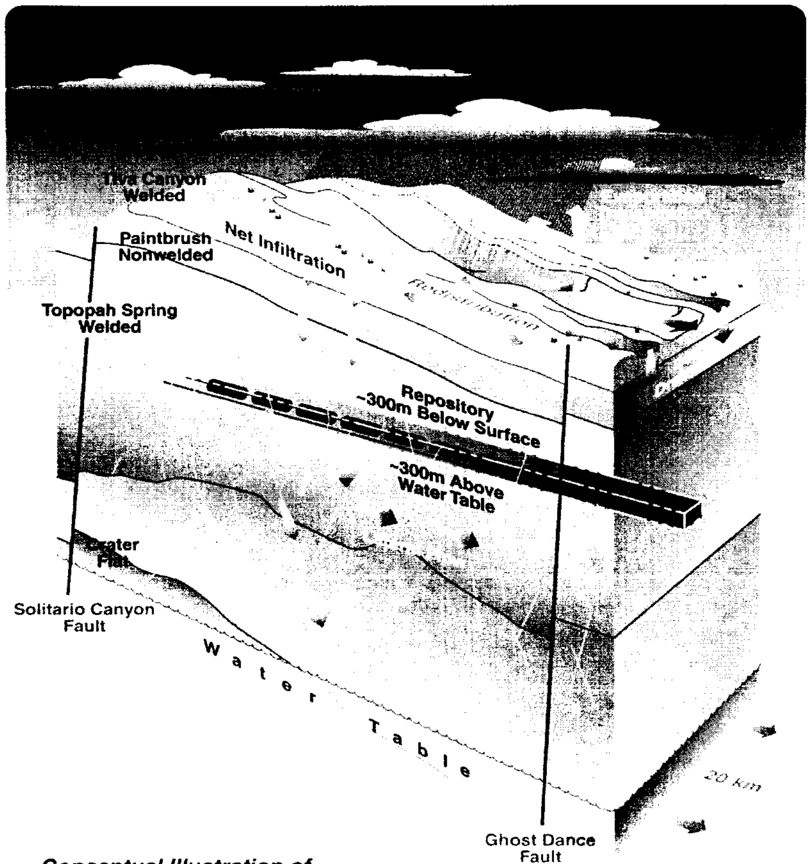
Scenario Analysis

- A systematic procedure of considering a comprehensive series of features, events, and processes (FEPs) pertaining to the system
- FEPs identified, categorized, screened off the initial list, new scenario classes formed, and scenario classes screened out from performance assessment
- FEPs that could materially affect compliance or have potentially adverse effects on performance are included
- Exclude events with annual probabilities below a threshold (in the United States)
- Important considerations
  - Strong technical justification for exclusion
  - Correctness of characterization and treatment of FEPs
  - Representativeness and variability of features

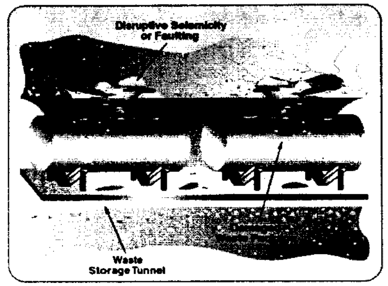
Abstracted Model Development

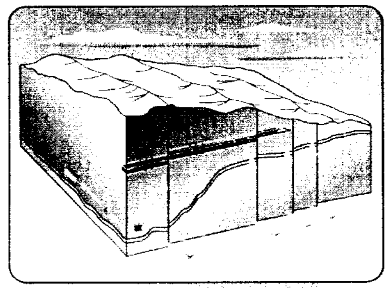
- The process of representing complex features of each scenario by a series of simplified models for a series of subsystems
- Abstraction Methods
- Key factors
  - Sufficiency of data and parameters to justify model abstraction
  - Characterization of model and uncertainty
  - Propagation of the effect of uncertainty through the abstracted model
  - Comparison of results from the abstracted model with the detailed model
  - Proper integration of models across the system model
- Submodel development should be based on stable results. Uncertainty can result from limited sample size

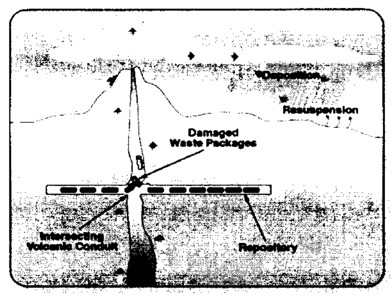
Conceptual Models of Yucca Mountain- Examples

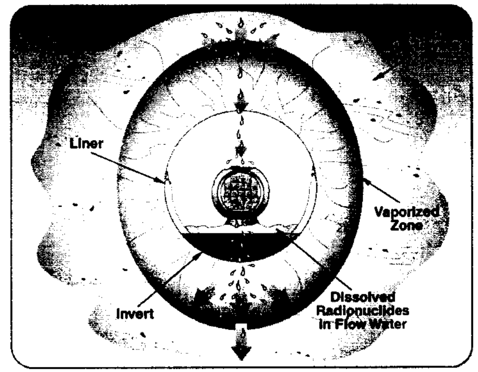


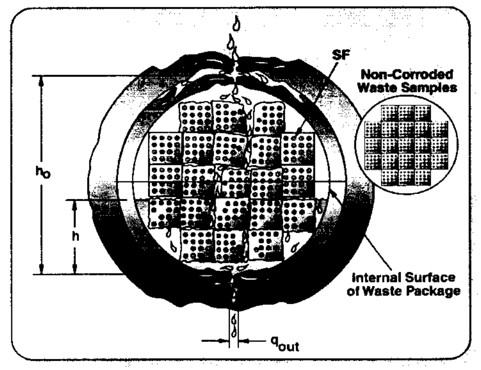
Conceptual Illustration of Unsaturated Zone Flow Processes at Different Scales











Model Integration

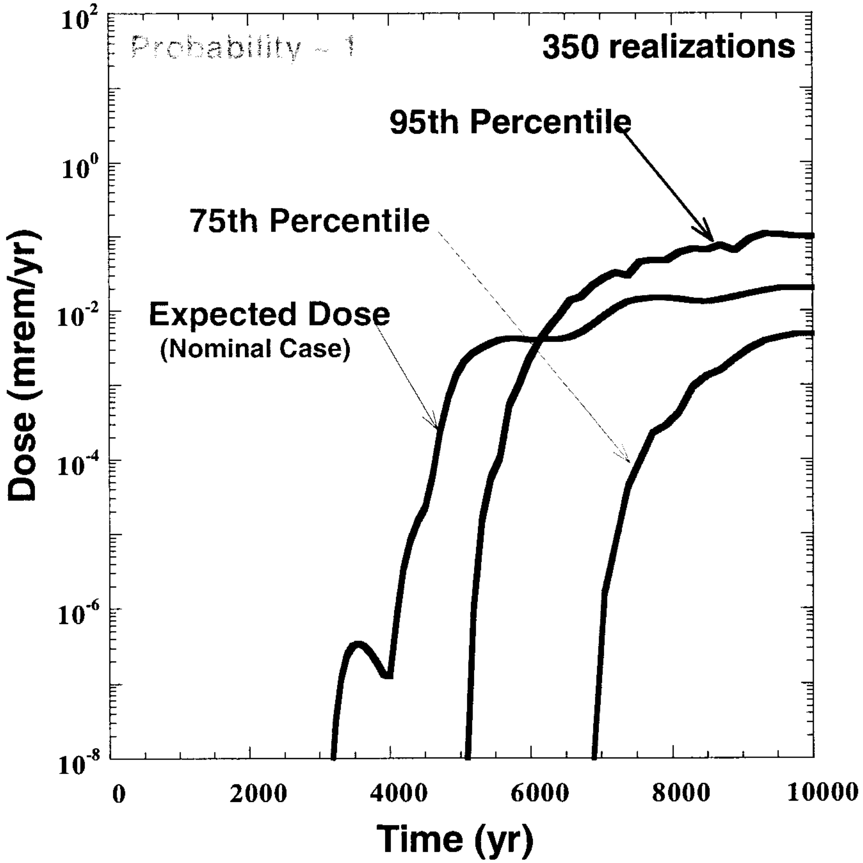
- Adequate incorporation of couplings
- Description of de-coupling during abstraction and re-coupling during integration
- Consistent and appropriate assumptions throughout the system model
- Testing
  - Variation of results with degree of spatial and temporal discretization
    - Mean highly affected by extreme values. Therefore, spatial resolution increase may be necessary to observe extreme conditions
  - Calculations are stable with respect to spatial and temporal discretization
  - Calculations are stable with respect to statistical variability

System-level Analysis

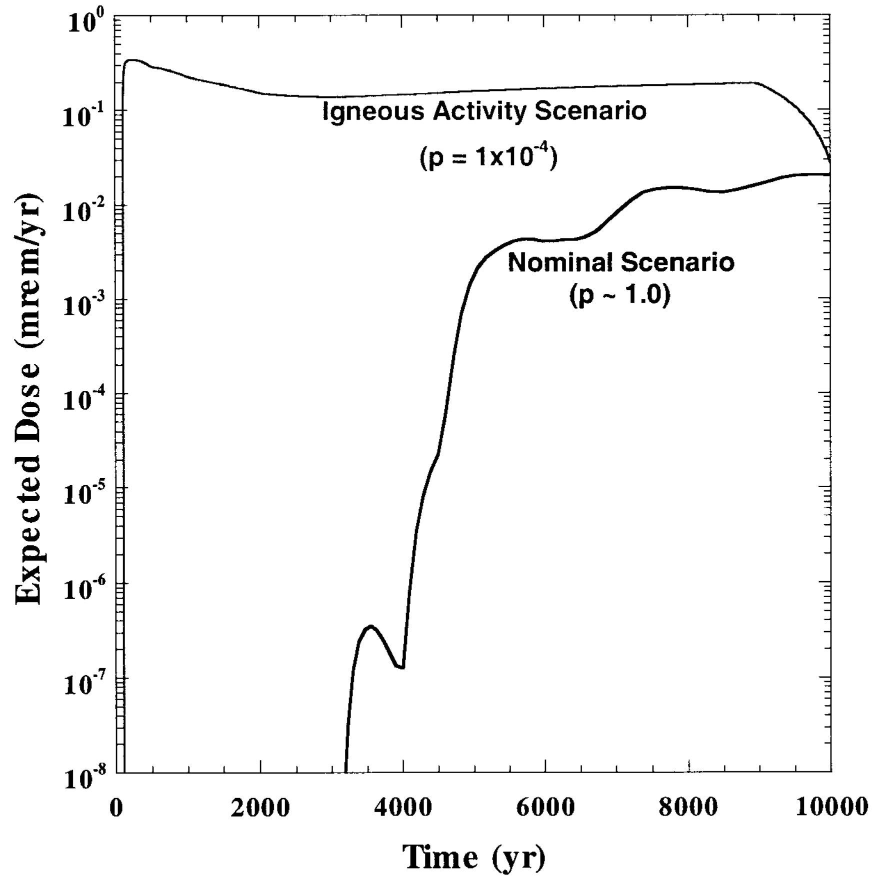
- Analyze consequences of individual scenarios to understand system behavior
- Deterministic vs. Probabilistic
- Probabilistic
    - -Compute performance with consideration of all appropriate uncertainties
    - -Monte Carlo approach
    - -High-probability (or basecase) scenario
    - -Low-probability scenarios
    - -Combining low-probability and high-probability scenarios
    - -Specialized analyses (e.g., human intrusion)
- Performance Measure
    - One performance measure needed for comparing repository subsystems performance on a common scale (risk-informing)
    - Performance measure for HLW disposal at Yucca Mountain:
        - Expected dose to a reasonably maximally exposed individual not to exceed a certain specified value
        - Additional standards: separate groundwater protection standards

Example System-level Results

Nominal Scenario



Disruptive Event Scenario



Defense-in-Depth Analysis

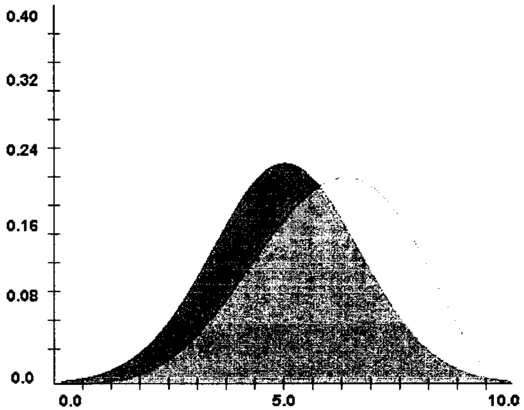
- Purpose: to gain insights regarding robustness and relative reliance on subsystems for safety
- Concept introduced to deal with uncertainty (similar to safety margin concept)
- Our ability to quantify risk is imperfect. Unquantified uncertainties could exist because of inadequate models
- Defense-in-depth analysis addresses "What if I am wrong"
- Key consideration:
  - Repository performance and the performance of individual components or subsystems should be consistent and reasonable
  - Important to account for parameter and model uncertainty
  - Important to document barrier capabilities in light of variability, independence, and interdependence of barrier functions

Uncertainty/Sensitivity Analyses

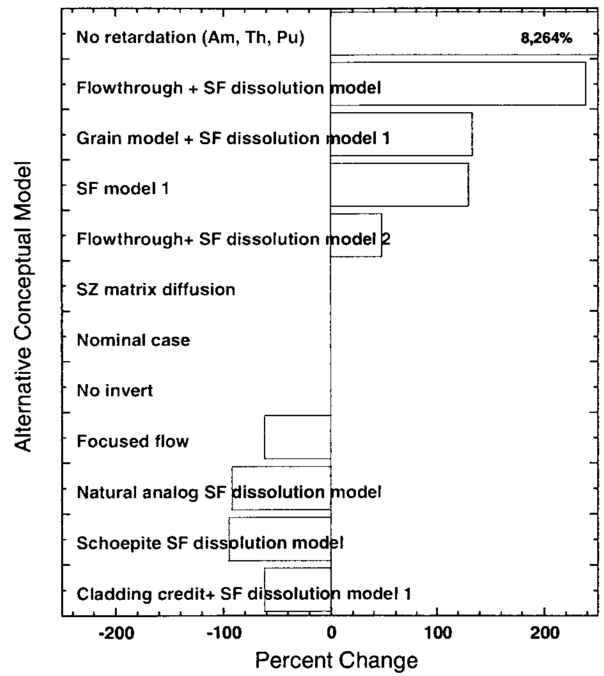
- Purpose: To identify parameters, models, subsystems, and factors that have dominant effects
- Sensitivity Analyses (local change in response with respect to a fixed change to a specified value of the input)
- Uncertainty importance analyses (performance uncertainty in response to input uncertainty)
- Robustness analyses (inputs set at 5th and 95th percentile, etc. values)
- Types of Analyses
  - Parametric sensitivity analysis
  - Distributional sensitivity analysis
  - Alternative conceptual model sensitivity analysis
  - Subsystem sensitivity analysis
    - Barrier component level analysis
    - Sub-process level analysis

Uncertainty/Sensitivity Analyses-Examples

Relative impact of the change of input distribution



Alternative Conceptual Model Sensitivity



Barrier Component Sensitivity

DS		DS	DS	DS	DS	DS
WP	WP		WP	WP	WP	WP
WF	WF	WF		WF	WF	WF
Invert	Invert	Invert	Invert		Invert	Invert
UZ	UZ	UZ	UZ	UZ		UZ
SZ	SZ	SZ	SZ	SZ	SZ	
0	34	62,200	61	6	1,980	90

Confidence Building (Validation)

- Purpose: Ensure the system model provides a credible representation of system performance
- Test/corroborate confidence in the system model
- Typically, traditional "scientific validation" is usually not sought
- Confidence to be built on
  - Software: correct performance of operations in the numerical model
  - Model: model correctly represents intended process or system
- Key considerations
  - A vision, philosophy, or strategy, verification plan, minimum requirements are important in the confidence building effort
  - Submodel validation may not be a surrogate for system-level validation
  - Peer-review may not be a substitute for reasonably available objective information

Validation (cont'd)

- Confidence building can be achieved through:
  - Laboratory and field experiments
  - Natural analogs
  - Computer code comparisons
- Performance confirmation program can play a key role

Performance Confirmation

- Purpose: evaluate the adequacy of model assumption, data, and analyses, and interactions that permitted construction of the repository and subsequent waste emplacement
  - Monitor the significant changes in the condition assumed in the license application that could affect regulatory compliance
  - Monitoring throughout site characterization, construction, emplacements and operation
- Confirm existing information (i.e., geologic conditions and parameter ranges)
- Confirm performance measures, relevance of collected data to geospatial discretization (scale of information);
- If parameters are out-of-range, those could affect performance assessment results—should have a back up plan

Summary and Conclusions

- An outline a risk assessment methodology for building a safety case for the disposal of high-level waste has been presented
- Probabilistic risk assessment rapidly gaining importance because of the risk-informed performance based regulation in many areas such as waste disposal, chemical, and food industries
- Sensitivity, uncertainty importance, and robustness analysis are important tools for understanding what drives performance of the system
- Model simplification is at the heart of performance assessment, but the process of simplification should be systematic and appropriately address uncertainties

Summary and Conclusions (cont'd)

- Intractable to represent all uncertainties and variability in performance assessment, but judicious use of the methodology presented could help retain important uncertainties and variabilities in the risk assessment model

- Documentation of uncertainties, abstractions, integration, and validations are key to a good risk assessment

- Software and assessment model validation is key to confidence building

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Comparative Risk Assessment and Environmental Decision Making

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WORKSHOP DIRECTOR

IGOR LINKOV
ICF Consulting
33 Hayden Avenue
Lexington, MA 02421,
USA
ilinkov@icfconsulting.com
ph: +781-6764053
FAX: +781-676-4061

CO-DIRECTOR

ABOU BAKR
RAMADAN
Egyptian Radiation and Environmental Monitoring Network
Nasr City 11762, P. O. Box 7551, Cairo, Egypt.
ph: +202 274 8787
Fax: +202 2878 662
ramadan58@yahoo.com

3 September 2002

Dr. Sitakanta Mohanty
Southwest Research Institute
P.O. Drawer 28510
San Antonio, Texas 78228-0510

Dear Dr. Mohanty

We would like to invite you to be a Key Speaker at the North Atlantic Treaty Organization (NATO) Advanced Research Workshop (ARW) entitled "Comparative Risk Assessment and Environmental Decision Making," to be held in Rome (Anzio), Italy, on 13-16 October 2002. The workshop will focus on how to use advanced risk analysis methodologies to make the best possible environmental policy decisions. It will address a critical problem in risk assessment: how to deal with uncertainty in both ecological and human risk evaluations. It is expected that 50 scientists from about 20 countries will attend the Workshop, which will contain both platform and poster sessions. Your paper is accepted for oral presentation. The workshop agenda and logistics will be sent to you within next three weeks.

Your presentation on "Risk Assessment in the Disposal of High-level Radioactive Waste – The Yucca Mountain Example" is accepted as an oral presentation. The conference Proceedings will be published by Kluwer Academic publishers as part of their NATO ASI series. NATO requires ARW Proceedings to be completed 3 months following the workshop. Therefore, we would like to have your complete contribution as soon as possible, but no later than the first day of the conference. We plan to have the contributions reviewed to assist in a clear and useful volume of proceedings and we will need to give the paper to the reviewer during the conference. Your paper should not be longer than 16 camera-ready pages.

Sincerely yours,

Igor Linkov, PhD
Workshop Director