Activities that Support the Scientific Credibility of Radioactive Waste System Performance Models

Presented to:
NRC Workshop on Engineered Barrier Performance Related to Low-Level Radioactive Waste, Decommissioning, and Uranium Mill Tailings Facilities

Session 5:
Experience with Model Support and Performance Confirmation to Gain Confidence in the Long-Term Performance

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An Invaluable Reference

- **Eisenberg, N.A.; Lee, M.P.; Federline, M.V.; Wingefors, S.; Andersson, J.; Norrby, S.; Sagar, B.; and Wittmeyer, G.W. 1999. *Regulatory Perspectives on Model Validation in High-Level Radioactive Waste Management Programs: A Joint NRC/SKI White Paper.* NUREG-1636. Washington, D.C.: U.S. Nuclear Regulatory Commission.**
- **Essentially concludes that validation is the aggregate of all activities used to support the modeling: it is confidence-building.**

An Example: Yucca Mountain Total System Performance Model

- **Volume II of the 2008 "TSPA-LA" model report is dedicated to demonstrating the basis for confidence in this model**

QA: QA

MDL-WIS-PA-000005 REV00

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Total System Performance Assessment Model/Analysis for the License Application

Volume II

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10 CFR 63.114 Requirements

- **A performance assessment used to demonstrate compliance must:**
  - **(1) Include data related to the geology, hydrology, and geochemistry (including disruptive processes and events) of the Yucca Mountain site, and the surrounding region to the extent necessary, and information on the design of the engineered barrier system used to define, for 10,000 years after disposal, parameters and conceptual models used in the assessment. . . .**
  - **(6) Provide the technical basis for either inclusion or exclusion of degradation, deterioration, or alteration processes of engineered barriers in the performance assessment, ...**
  - ***(7) Provide the technical basis for models used to represent the 10,000 years after disposal in the performance assessment, such as comparisons made with outputs of detailed process-level models and/or empirical observations (e.g., laboratory testing, field investigations, and natural analogs).***

Model-Support Activities Should Reflect the Potential Disposal Facility Risk

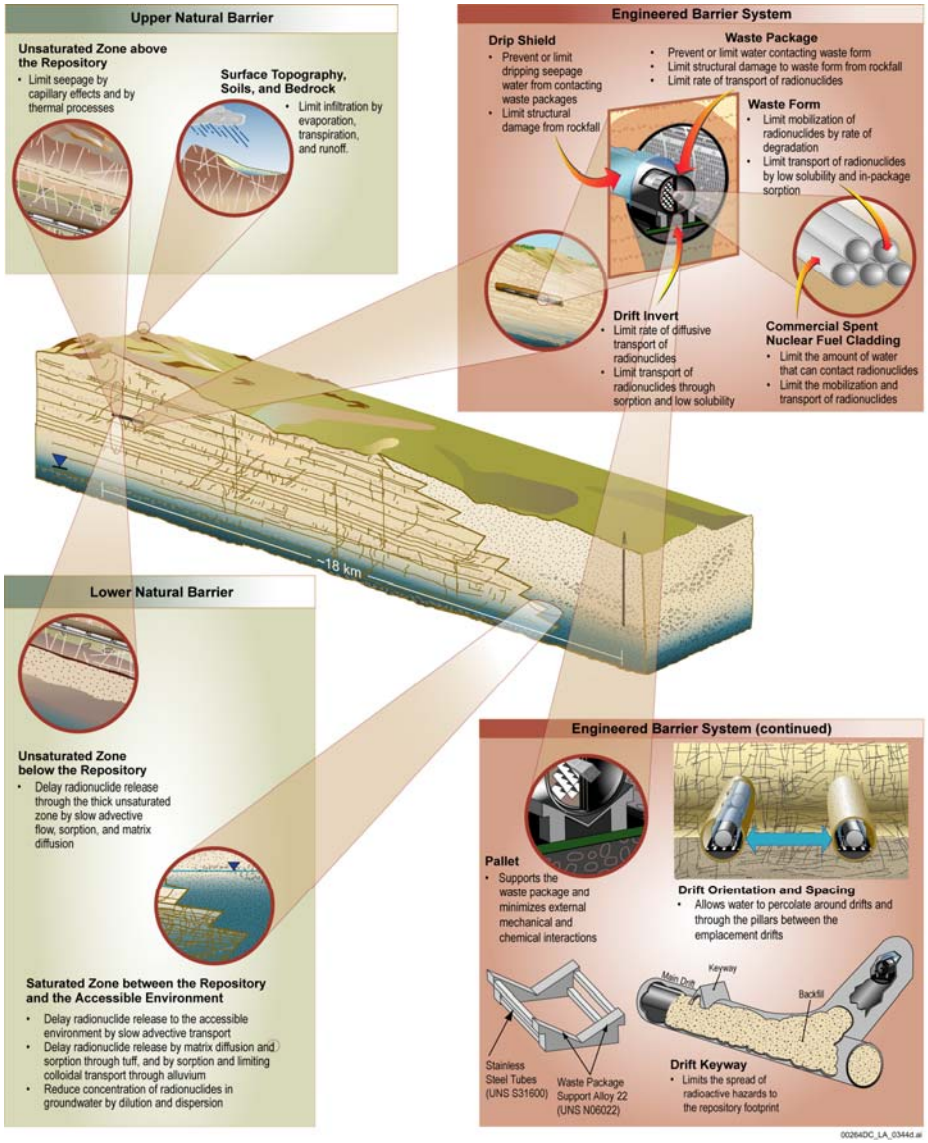
- **For a system that isolates lower-radioactivity-level wastes, the volume of material needed to support calculations of performance would be much less, but the supporting activities would be broadly similar**

- **There is opportunity to share approaches, and even models and scientific study results for similar structures and facilities**
  - **There are past, present, and future, as well as domestic and international, radioactive waste facilities whose safety assessments can serve as analogues for each other**
  - **There is no need to re-invent what already exists, but in a "nuclear-safety culture" there is a need to continually question and seek to improve what exists**
  - **International cooperation can and does save domestic resources, and is a confidence-building activity in and of itself**

Model Validation Approach

- **During-development Confidence-Building Activities**
  - **Verification of inputs, software, submodel implementation, and submodel coupling**
  - **Model stability testing: statistical stability, numerical accuracy, temporal stability, spatial stability**
  - **Uncertainty characterization reviews**
- ***Post-development Confidence-Building Activities***
  - ***Corroboration of abstraction model results with the results of process-level models***
  - ***Corroboration with auxiliary analyses***
    - ***Deterministic single realization analyses***
    - ***Comparison of TSPA Model results to EPRI PA results***
    - ***Performance Margin Analysis (PMA): remove key conservatisms***
  - ***Corroboration with natural analogue information***
  - ***Technical review***
  - ***Performance confirmation monitoring and testing***

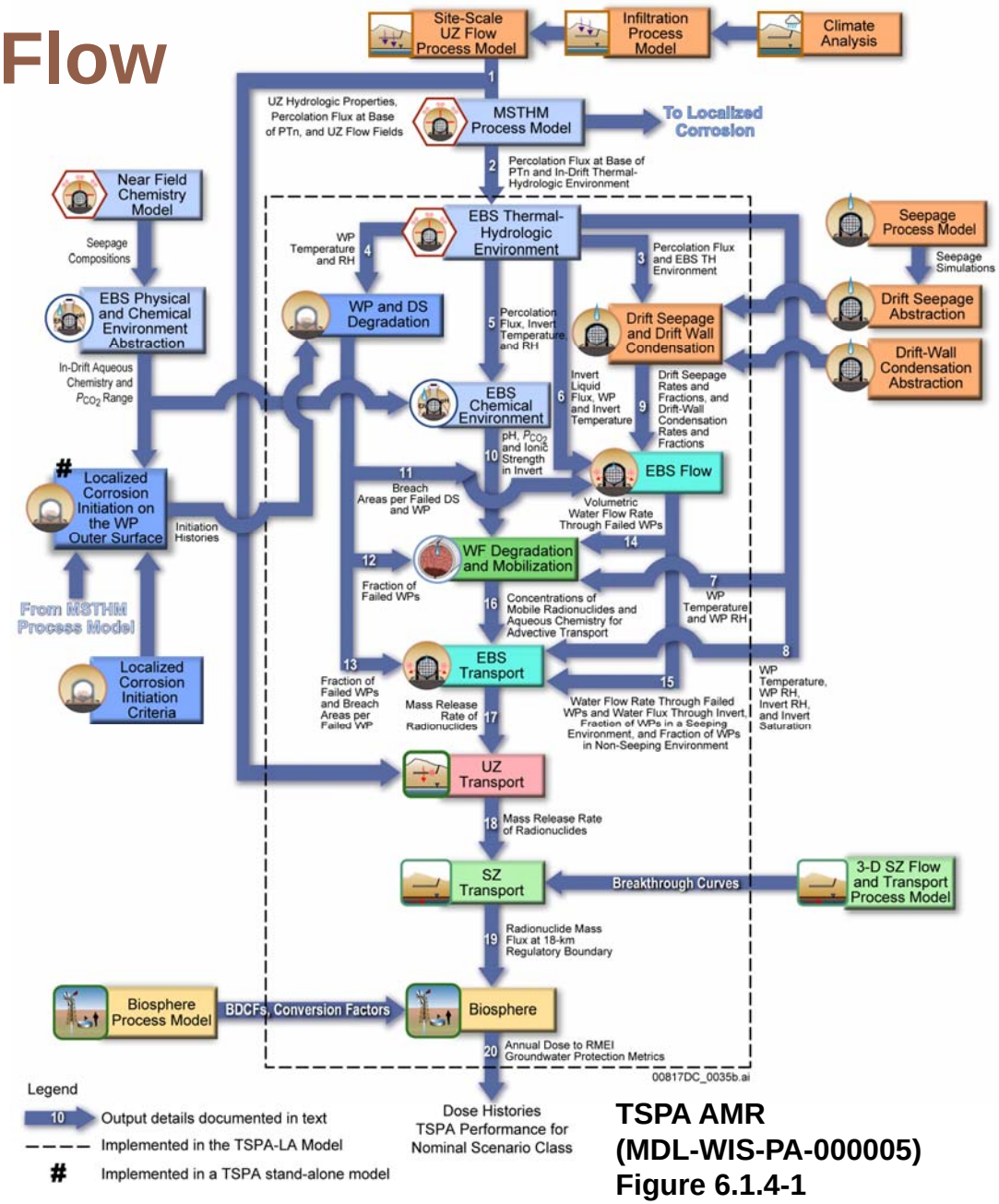
Barriers, Features, and Components



- **Features and Components**
  - **Surface soils and topography**
  - **Unsaturated zone above the repository**
  - **Drip shield**
  - **Waste package**
  - **Cladding**
  - **Waste form**
  - **Invert**
  - **Unsaturated zone below the repository**
  - **Saturated zone**

TSPA Information Flow

- **Nominal scenario class**
- **Shows primary types of information passed from process models to TSPA abstractions, and among TSPA abstractions and submodels**
- **Other diagrams are applicable to early-failure, seismic, and igneous scenario classes**
- **TSPA AMR Sections 6.1.4 and 6.3.X**



TSPA AMR (MDL-WIS-PA-000005) Figure 6.1.4-1

Post-Development Model Validation Activities

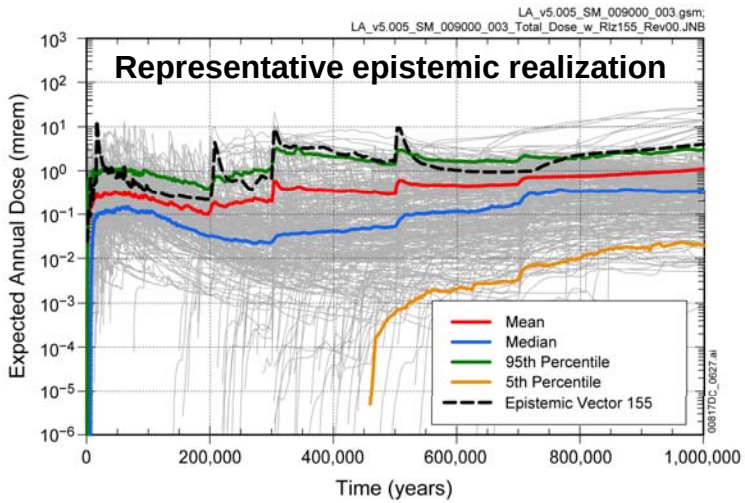
- **Corroboration of results with auxiliary analyses**
  - **Single realization analysis**
  - **Comparison to independent EPRI IMARC analysis**
  - **Performance Margin Analysis (PMA)—effect of key conservatisms**

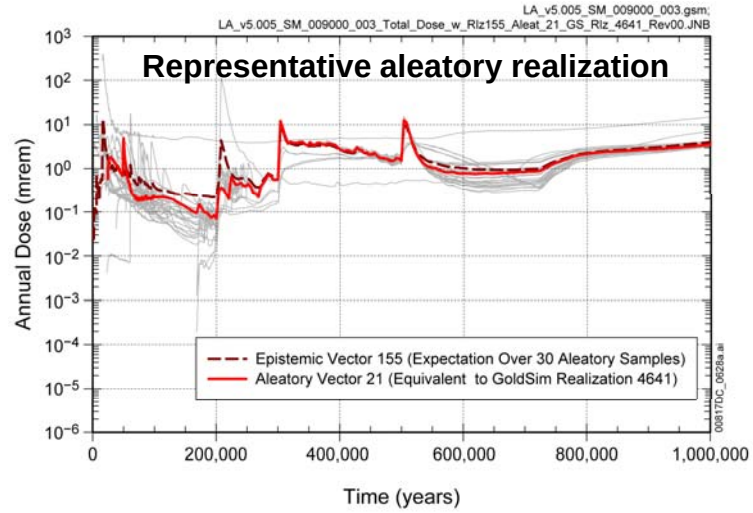
Single Realization Analysis

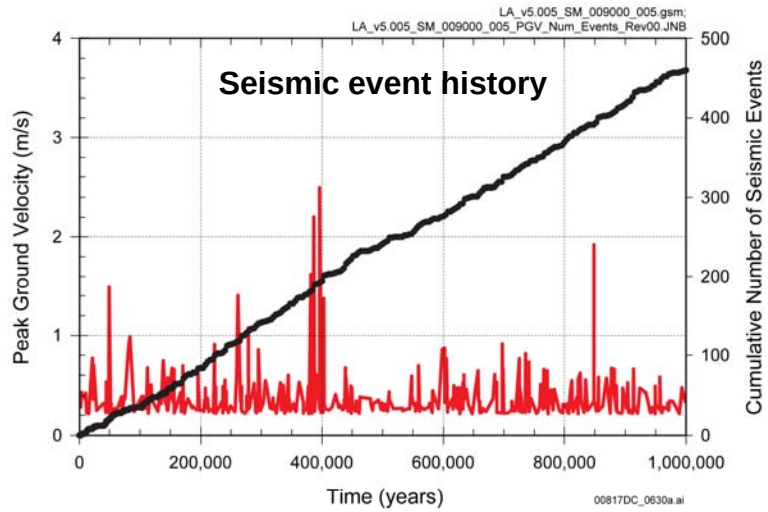
- **Provide insight into submodel coupling**
- **Investigates the interactions and cause-effect relationships between model components**
- **Comprehensive understanding of the performance of the system**
- **Error-checking and model verification**
- ***Example shown is somewhat analogous to an evaluation of an engineered disposal site cover over time***

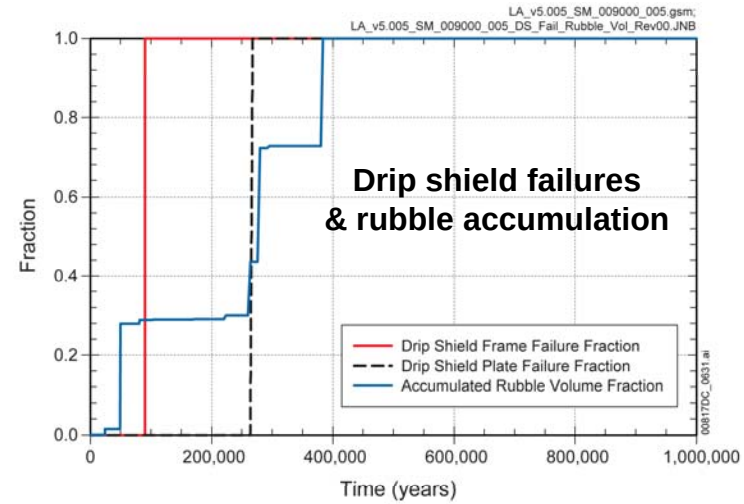
Single Realization Analysis:

1,000,000-Year Seismic Ground Motion Modeling Case







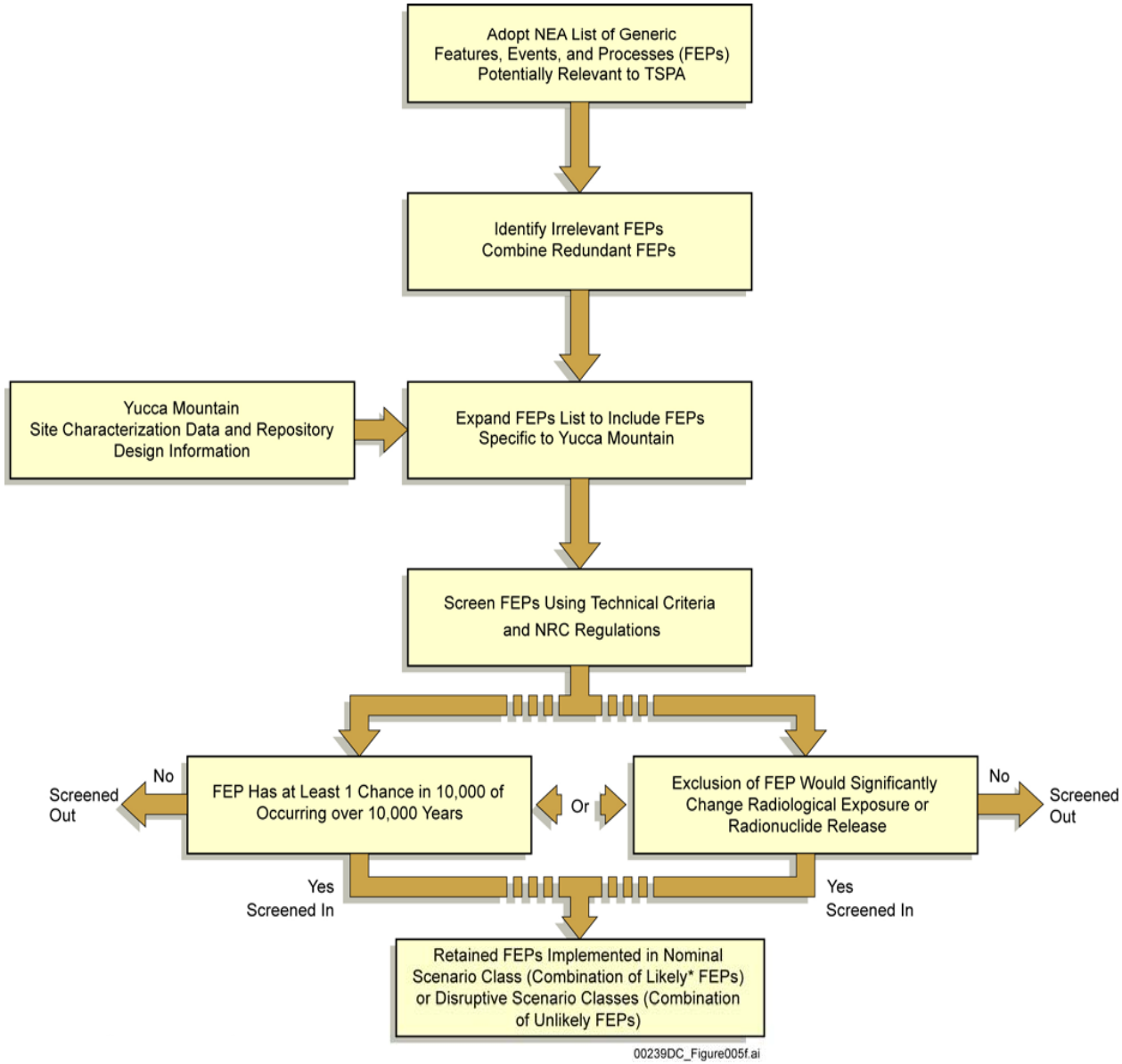


Illustrative figures from TSPA AMR (MDL-WIS-PA-000005), Figures 7.7.1-52[a], 53[a], 55[a], and 56[a]

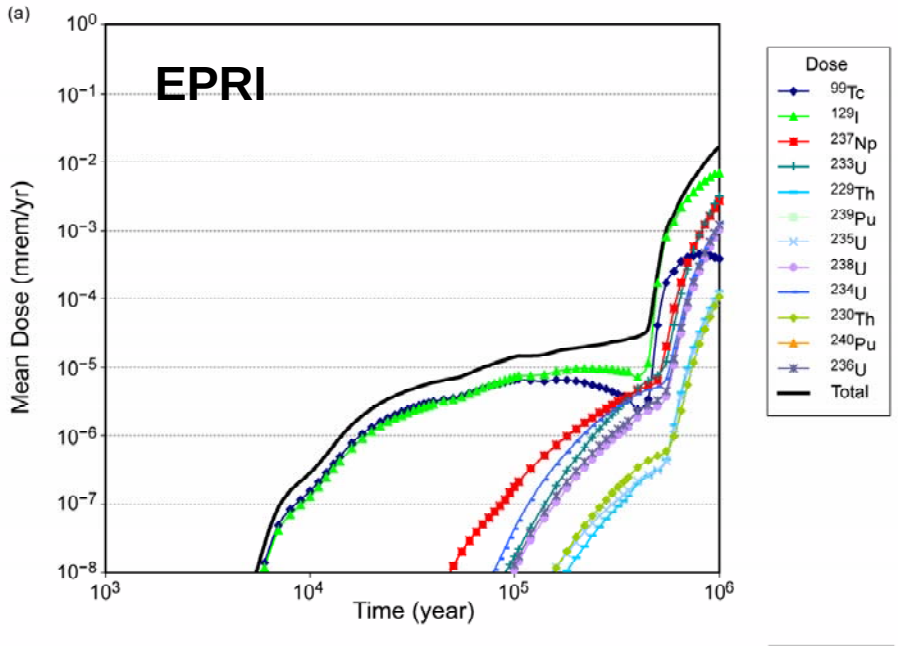
EPRI Analysis

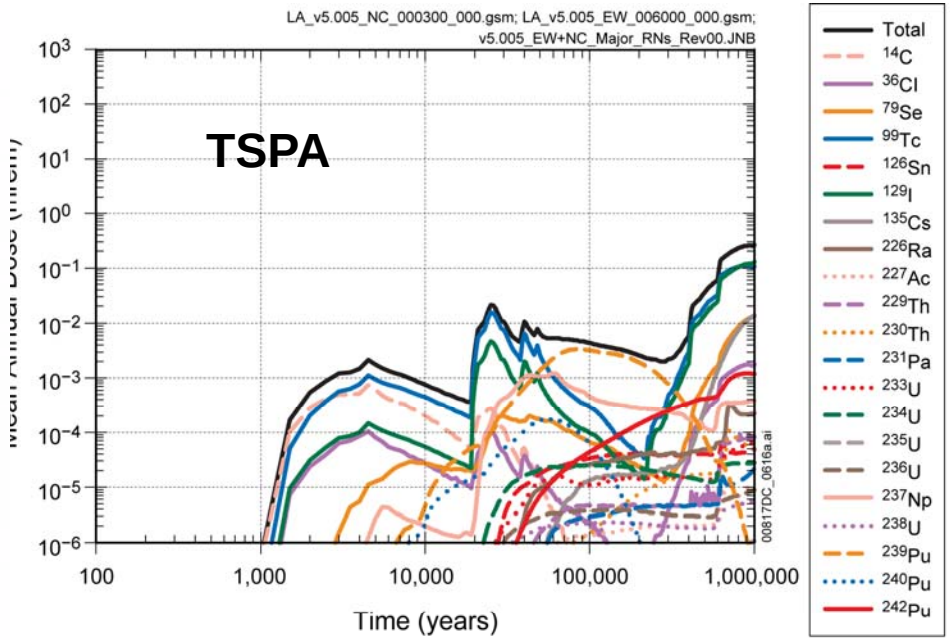
- **Independent third-party assessment of key technical and scientific issues**
  - ***Like making a comparison with an independent safety evaluation of an analogous waste disposal system, domestic or international***
- **Logic-tree vs. Monte Carlo sampling-based**
- **Same model components and features, events and processes (FEPs—see next page for FEP-definition approach used)**
- **Differences in the results were explained by determining differences between the two models**

FEPs Evaluation Process



Comparison to EPRI Analysis





- **Nominal Plus Early Failure Waste Packages**
- **At 1,000,000-yrs dose results are comparable**
- **^{129}I and ^{99}Tc are significant dose contributors in both PAs**

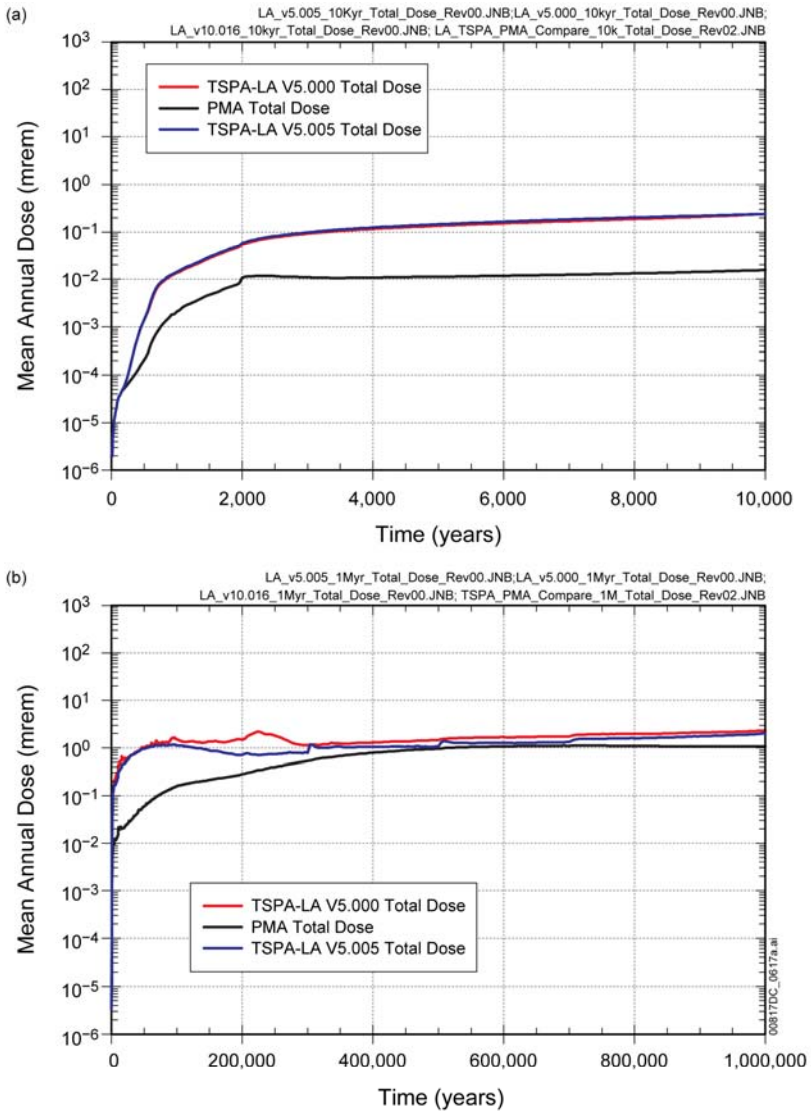
Illustrative figure on the right from TSPA AMR (MDL-WIS-PA-000005), Figures 7.7.3-3[a]

Performance Margin Analysis

- **Include less conservative alternative conceptual models**
- **Narrower parameter uncertainty distributions in cases where conservative bounding values were assumed**
- **Includes additional coupling among different physical and chemical processes**

Performance Margin Analysis

- **Submodel conservatisms propagated through the total system do not underestimate the total mean annual dose**
- **PMA dose is more than a factor of 10 lower at 10,000 years and a factor of 2 lower at 1,000,000 years**
- **The evaluated conservatisms do not introduce any risk dilution in TSPA results**



Illustrative figure from TSPA AMR (MDL-WIS-PA-000005) Figure 7.7.4-7[a] (a and b)

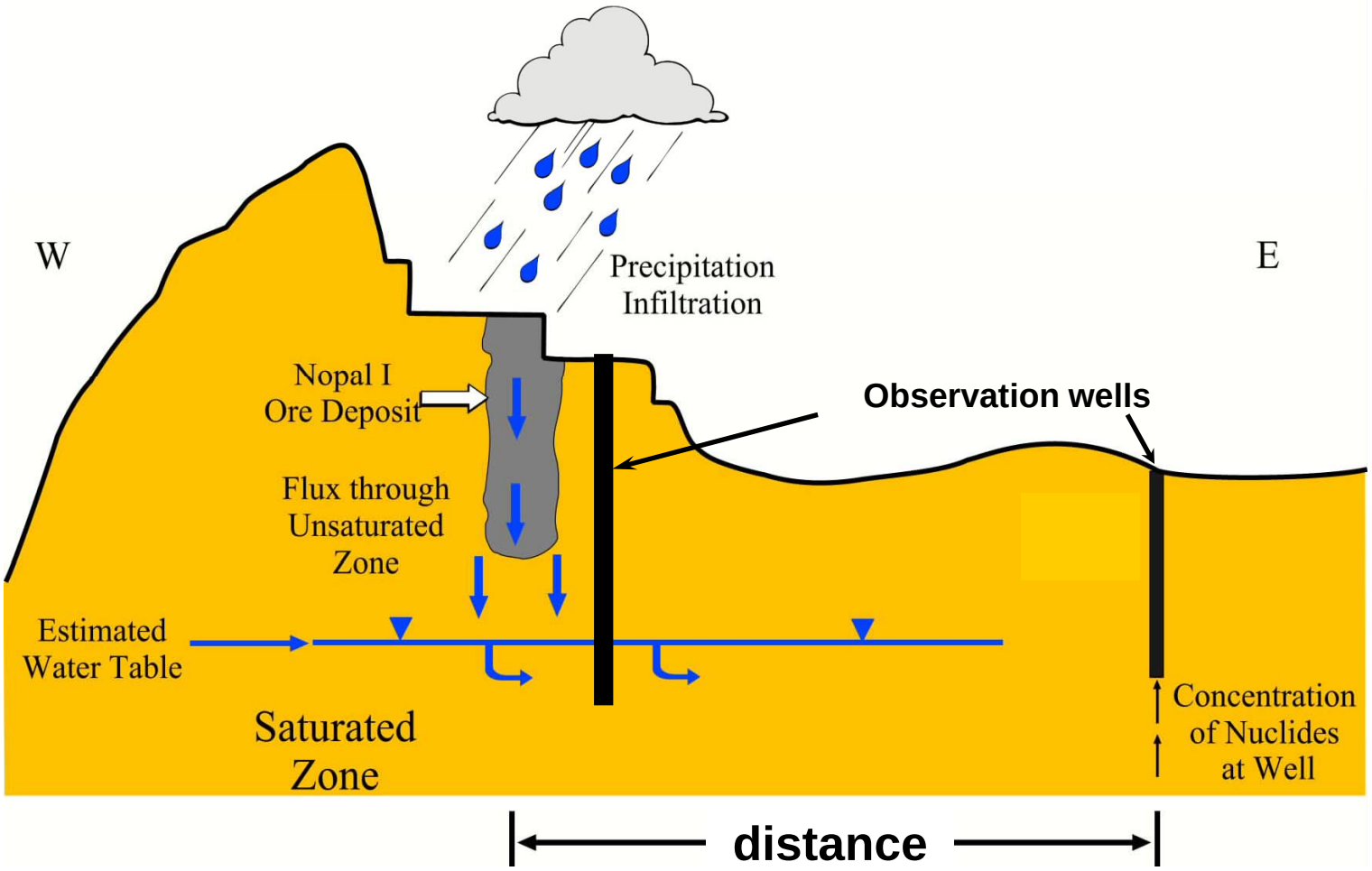
Natural Analogues

- **Compare repository conditions and materials to observed conditions and materials for time periods relevant to the lifetime of the repository**
- **Provide insights and build confidence in the conceptual and numerical models used to represent processes and events**
- **TSPA analogues**
  - **1995 volcanic eruption at Cerro Negro, Nicaragua**
  - ***Radionuclide transport at the Nopal I uranium deposit in the Sierra Peña Blanca in Chihuahua, Mexico***

Natural Analogues – Peña Blanca

- **Analogue for the evolution, fate, dissolution and transport of SNF placed in the repository**
- **Uranium deposit is geologically, climatically, geochemically, and hydrologically analogous to Yucca Mountain**
- **Hydrogeologic and geochemical investigations at Nopal I indicate that there has been relatively little transport of the radionuclides from the ore deposit and that few radionuclides have traveled very far from their sources**
  - **Modeling the Ra-222, Pb-210, and Po-210 contents of well-water samples indicates that migration rates of these isotopes are three to six orders of magnitude slower than groundwater movement rates**

Peña Blanca Conceptual Model



A Potential Analogue for Explaining How an Engineered Cover Protects Against Infiltration?

- **Natural analogues: rock openings and caves have been studied in terms of the annual rainfall and amount of infiltration at depth**
- **Antropogenic analogues: Chinese burial sites and earthen dams --effective because of layering of materials of differing porosities**

Seepage into a Cave

14,000 year old painting of a bison from Altamira

A 22-month study showed that <1% of the infiltration from the surface became seepage into the cave

Independent Technical Review

- **Successive iterations of the TSPA model have been subject to independent reviews by technical staff and various external organizations**
- **During the development of subsequent iterations of the TSPA model, recommendations from the technical review of the preceding iterations are considered**
- **In addition to routine NWTRB reviews, three recent technical reviews include**
  - **TSPA-VA model peer review conducted in 1999**
  - ***TSPA-SR model review by an international a joint International Atomic Energy Agency (IAEA) and Organisation for Economic Co-operation and Development Nuclear Energy Agency (OECD/NEA) review team in 2002***
  - **TSPA-LA draft model review by an independent validation review team completed in 2006**

“An International Peer Review of the Yucca Mountain Project TSPA-SR”

- **This joint IAEA/OECD-NEA review observed:**
  - **. . . the general approach to TSPA, and the USDOE approach of building on an iterative series of performance assessments conform to international best practice. . . .**
  - **. . . structure of the TSPA-SR methodology, and . . . [the] approach of building on an iterative series of performance assessments, conform to international best practice.**
  - **The structured abstraction process linking process-level models to assessment models is at the forefront of international developments.**
  - **. . . the FEP methodology. . . [is] in agreement with international best practice, . . .**
  - **. . . does not emphasize natural analogues as much as in some other international studies.**
  - **“While presenting room for improvement, was soundly based and has been implemented in a competent manner.”**

Performance Confirmation Monitoring and Testing

- **Performance confirmation is a program of monitoring, tests, experiments, and analyses conducted to evaluate the adequacy of the information used to demonstrate safety**
- **A performance confirmation program should demonstrate that the system and the sub-system components (i.e., barriers) are operating as anticipated via monitoring**

A Decision Analysis Approach Was Used

- Explicitly acknowledged that tradeoffs among different objectives and goals may be necessary
- Used a formal multi-attribute utility analysis in its first phase to develop test and monitoring "portfolios" to be used in a second phase
  - A technically sound mathematical approach for evaluating alternatives where more than one objective is important
  - Has been used by federal agencies, and private companies since the late 1970s to evaluate complex decision problems
- The second phase involved management reviews and adjustments stemming from applying value-judgments
- A final and continuing phase would have been the periodic reevaluation and updating of this plan

Phase 1: Evaluating Candidate Activities

Develop evaluation criteria

- **Sensitivity** of barrier capability & system performance to the parameter
- **Confidence** in the current representation of the parameter
- **Accuracy** with which the proposed activity measures or estimates the parameter

Assign management value judgments to criteria

- Provides weighting function to criteria

Define and describe candidate performance confirmation activities

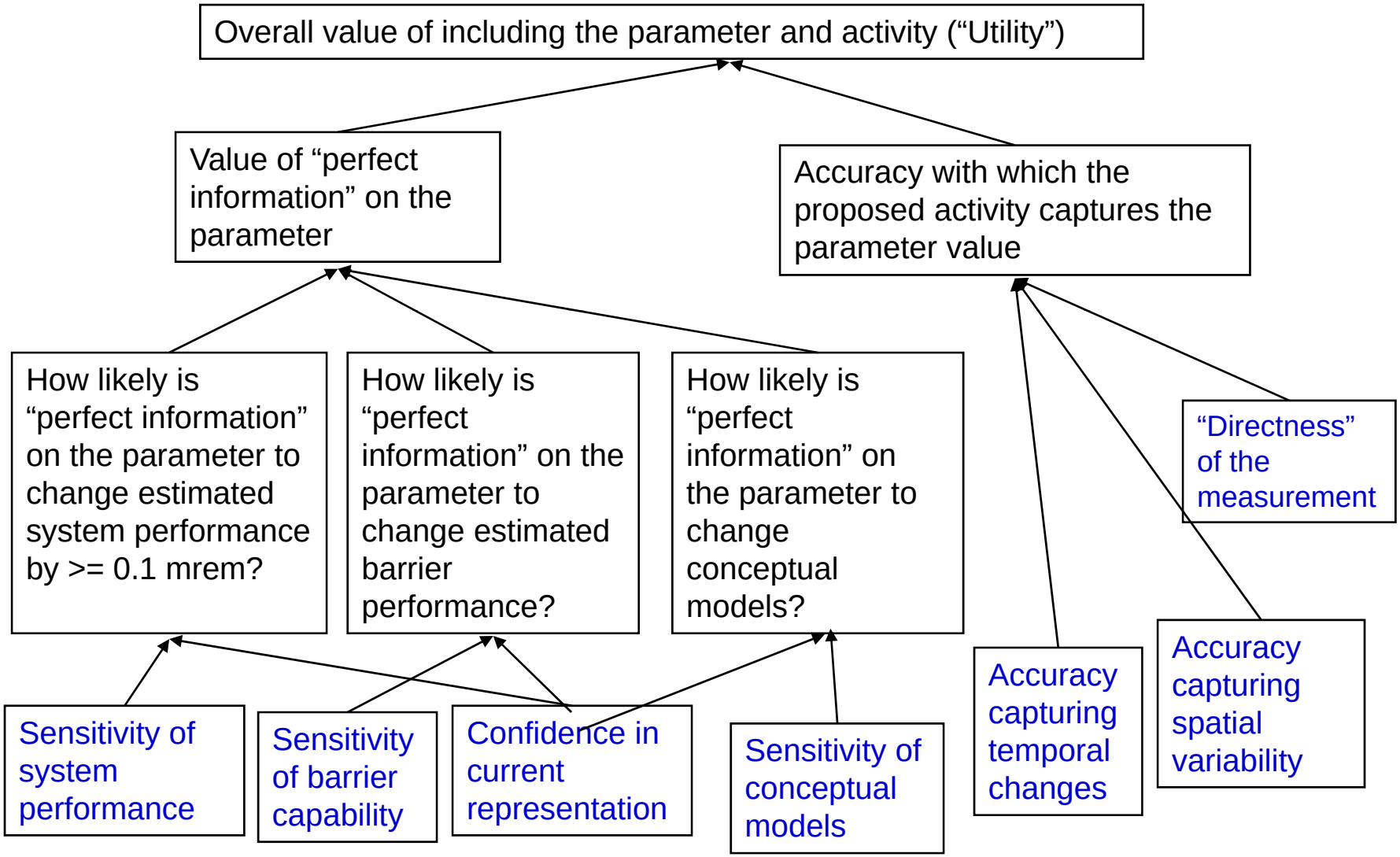
Evaluate activities (technical judgments using evaluation criteria)

Combine technical activity evaluation and management value judgments to get overall utility for each candidate activity

Activity Evaluation Criteria

- **At an initial workshop three criteria were defined, to be used in estimating the potential impact of a performance confirmation activity on the performance confirmation program:**
  - **System performance sensitivity to the parameter**
  - **Confidence in the current representation of the parameter**
  - **Accuracy of proposed activity's measures or estimates**
- **At subsequent workshops specialist groups developed a comprehensive list of parameters to be considered**
- **For each parameter identified, the group defined one or more data acquisition methods that could be implemented to provide information on that parameter**
- **Technical program managers brought management values into consideration**

Estimating the Utility of a Specific Activity



Phase 2: Developing and Evaluating Alternative Portfolios

Develop portfolio philosophies → **Define activities included in each portfolio** → **Evaluate portfolios**

- Basic requirement: any portfolio must meet regulatory requirements
- Beyond the basic requirement, consider portfolios defined around:
  - –Cost-effectiveness
  - –Testing specific hypotheses
  - –Maximizing regulatory robustness and coverage
  - –Maximizing in situ activities
  - –Maximizing off-footprint activities
  - –Maximizing use of pre-emplacement data

- Using the results of Phase 1, assign activities to portfolios based upon the portfolio philosophy.

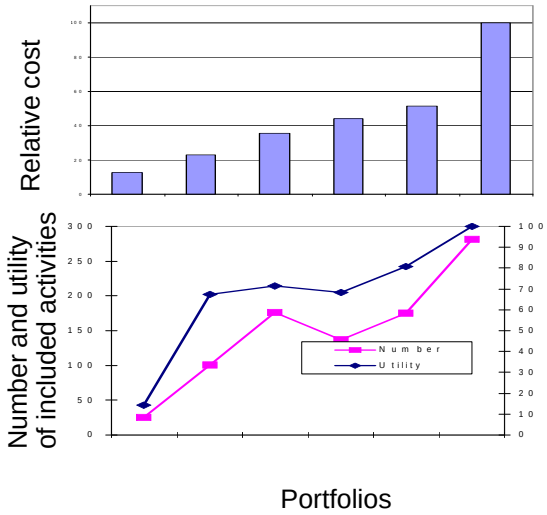
Portfolio A

Activity 1
Activity 2
Activity 6
Activity 12
Activity 22
. . .

Portfolio B

Activity 1
Activity 3
Activity 4
Activity 6
Activity 11
. . .

- Portfolios are compared in terms of regulatory robustness, overall utility scoring (cost effectiveness), and cost.



Phase 3: Selecting the Portfolio

Select the portfolio → **Reevaluate the activities (as a whole) included in each portfolio** → **Document the Performance Confirmation Program**

– Management selected a base portfolio using a cost-effectiveness philosophy

– The base portfolio was modified to increase its regulatory robustness and coverage, using information from the hypothesis-testing philosophy

– Activities were removed if they were more appropriate for other testing programs

– Activities were removed if they were focused on phenomena not included in the system-level model

– An activity was added to compensate for lack of coverage due to a removed set of activities

– An activity was added to increase the spatial representativeness of thermal test data

– *Performance Confirmation Plan* documents the performance confirmation program development

Phase 4: Updating the Program

Reevaluate the program activities as needed → **Document the Performance Confirmation Program**

- Activities would have been added, modified, or changed based on new information

- *Performance Confirmation Plan* documents Phases 1 through 4 of performance confirmation program development

20 Activities were selected for the initial performance confirmation program for the formerly proposed Yucca Mountain repository