SAND2012-9836P

National Level Site Evaluation Considerations, Processes and Criteria: US Case Studies

Performance Assessment Methodologies

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Today's Discussion

- Role of Performance Assessment in the Case for Safety
- Evolution of Performance Assessment
- "ABCs" of Performance Assessment
- U.S. Case Studies

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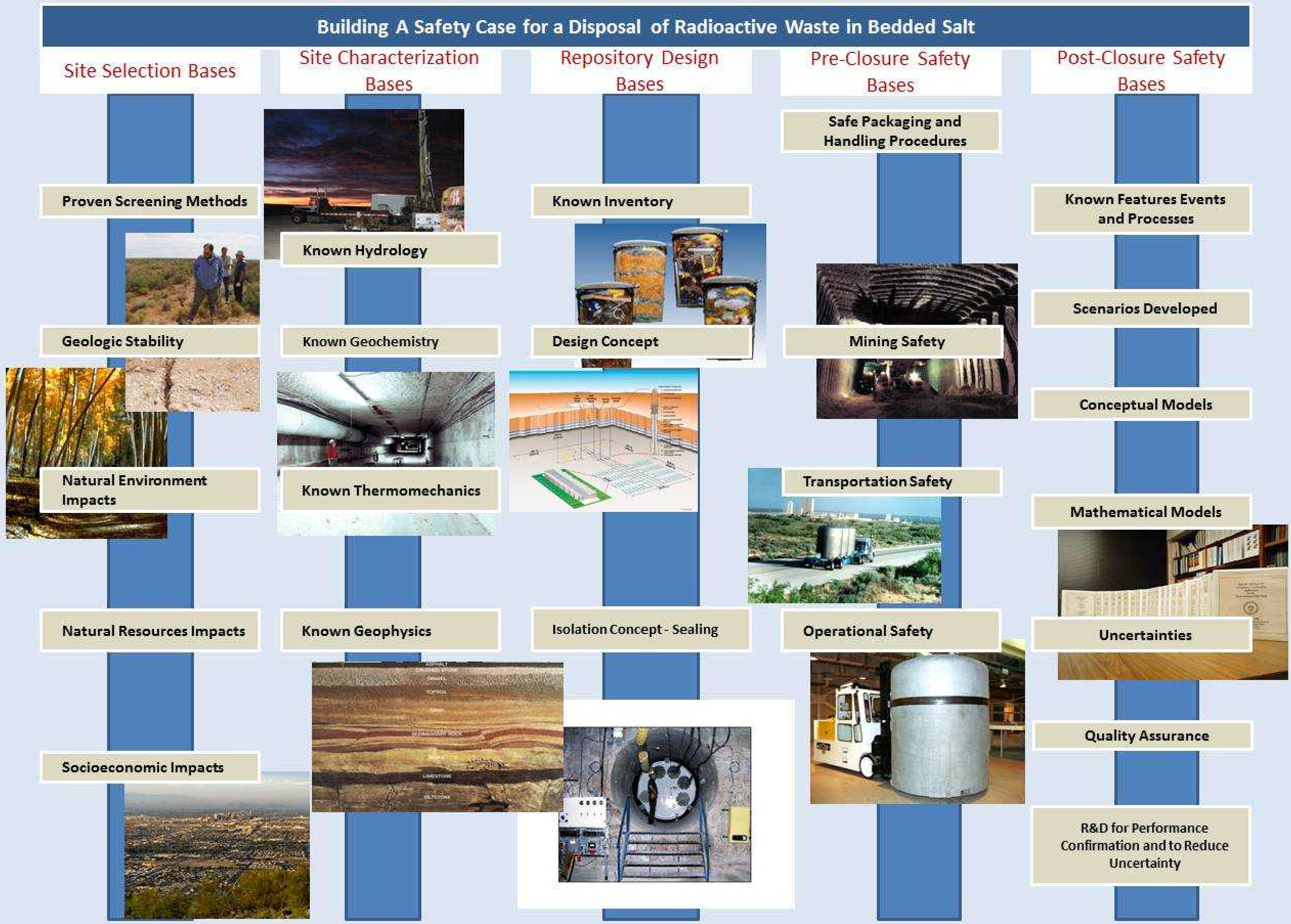

Building A Safety Case for a Disposal of Radioactive Waste in Bedded Salt
Site Selection Bases
Proven Screening Methods
Geologic Stability
Natural Environment Impacts
Natural Resources Impacts
Socioeconomic Impacts
Site Characterization Bases
Known Hydrology
Known Geochemistry
Known Thermomechanics
Known Geophysics
Repository Design Bases
Known Inventory
Design Concept
Isolation Concept - Sealing
Pre-Closure Safety Bases
Safe Packaging and Handling Procedures
Mining Safety
Transportation Safety
Operational Safety
Post-Closure Safety Bases
Known Features Events and Processes
Scenarios Developed
Conceptual Models
Mathematical Models
Uncertainties
Quality Assurance
R&D for Performance Confirmation and to Reduce Uncertainty

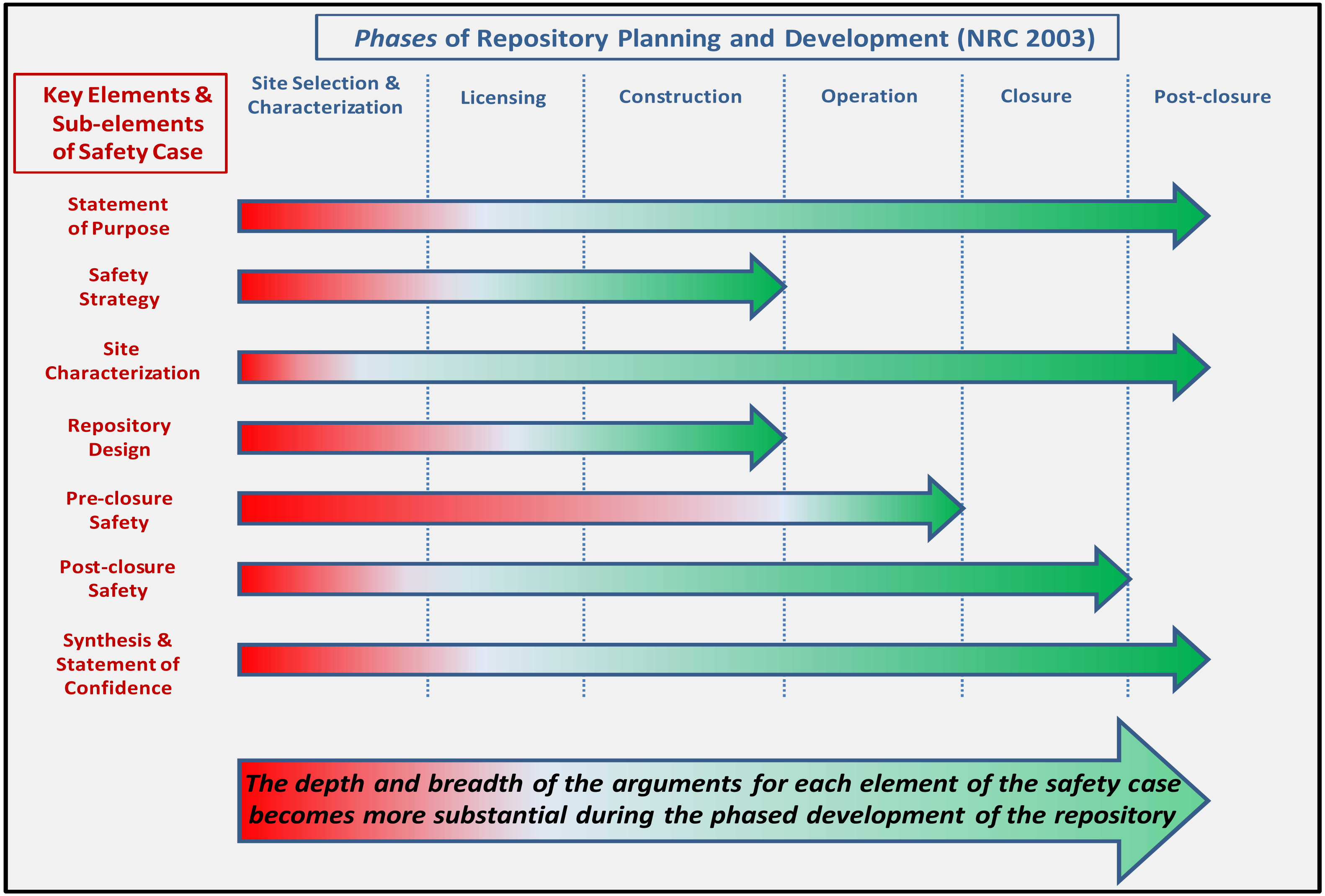
The Role of PA in the Case for Safety

- Performance Assessment (PA) is
  - a probabilistic risk analysis of a radioactive waste disposal facility used to demonstrate that performance objectives for long-term protection of human health/environment will not be exceeded following permanent closure of the facility
- Sandia National Laboratories (SNL)
  - has played a key role in development/implementation of total system analyses of waste management systems for over 30 years

Role of PA in the Case for Safety

- **In early stages, characterization program is broad-based and focused on gaining an adequate understanding of the system (waste, facility, and site) and identifying greatest sources of uncertainty**
- **As knowledge and understanding of the system improve, features, events and processes (FEPs) can be developed/ screened and scenarios can be developed/analyzed**
- **Conceptual and mathematical models are developed based on relevant (included) FEPs**
- **Probabilistic modeling is conducted, taking into account both parameter uncertainties and scenario uncertainties, to generate estimates of performance**
- **Sensitivity analysis is conducted and scenario assumptions and parameters with greatest impact on performance measures are identified and prioritized**
- **R&D activities that produce reasonable reductions in uncertainty are funded while other activities are terminated or scaled back**
- **Iterative– new information used to refine requirements, performance measures, alternatives, and models**

Role of PA in the Case for Safety



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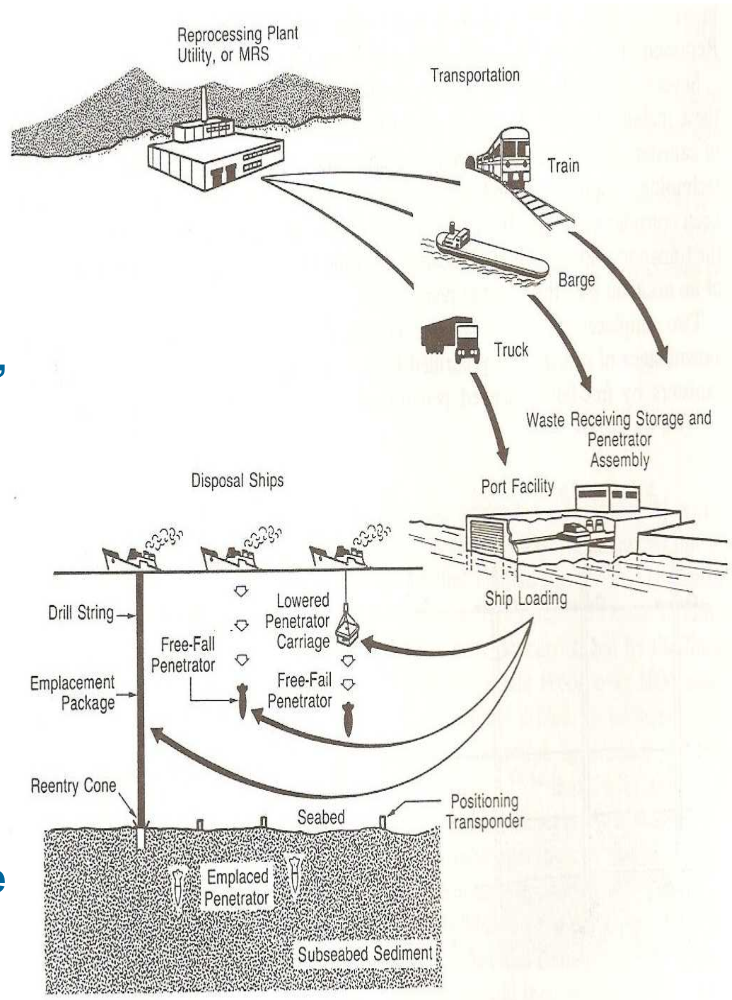
Evolution of Performance Assessment

- Conceived and Developed Over 30 Years Through a Number of Programs

  - **International Subseabed Disposal Program (SDP)**
  - **Development/demonstration of high-level waste (HLW) PA methodology for a bedded salt repository for U.S. Nuclear Regulatory Commission (NRC)**
  - **Development/demonstration of HLW PA methodology for a basalt repository for NRC**
  - **Development/demonstration of low-level waste (LLW) PA methodology for shallow trench burial for NRC Development/implementation of the**
  - **Waste Isolation Pilot Plant (WIPP) PA for the U.S. Department of Energy (DOE)**
  - **Development/implementation of the Yucca Mountain (YM) Total System PA (TSPA) for DOE**
  - **Evaluation of two generic geologic repositories for disposal of HLW and spent nuclear fuel (SNF) stored at Idaho National Laboratory (INL) for DOE**
  - **Development/implementation of PAs for disposal of special-case wastes in Greater Confinement Disposal (GCD) boreholes for DOE**

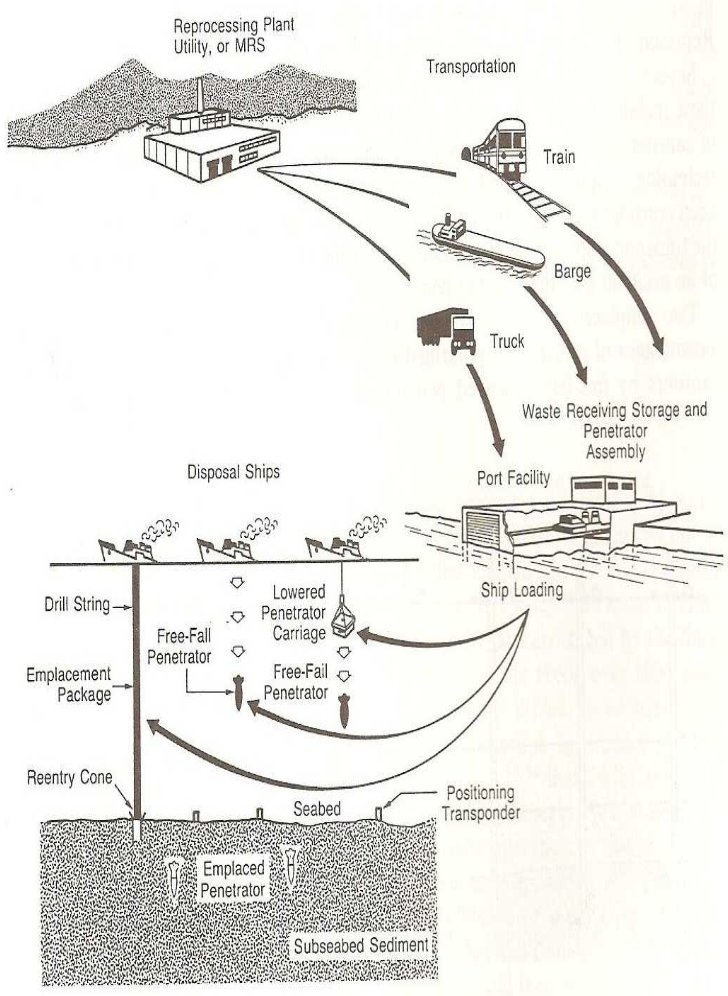
Subseabed HLW Disposal System

- **First implementations of the PA methodology performed by SNL (1973-1987) for DOE**
- **Scenarios for analysis were developed**
- **Process models were developed for components of the system, abstractions generated and linked, and annual PA calculations were performed**
- **Results of iterative PAs focused work on important processes and pathways**
- **Identified the need for a list of features, events, and processes (FEPs) acting upon the disposal system**
- **Demonstrated how to develop scenarios from the identified FEPs**



Subseabed HLW Disposal System

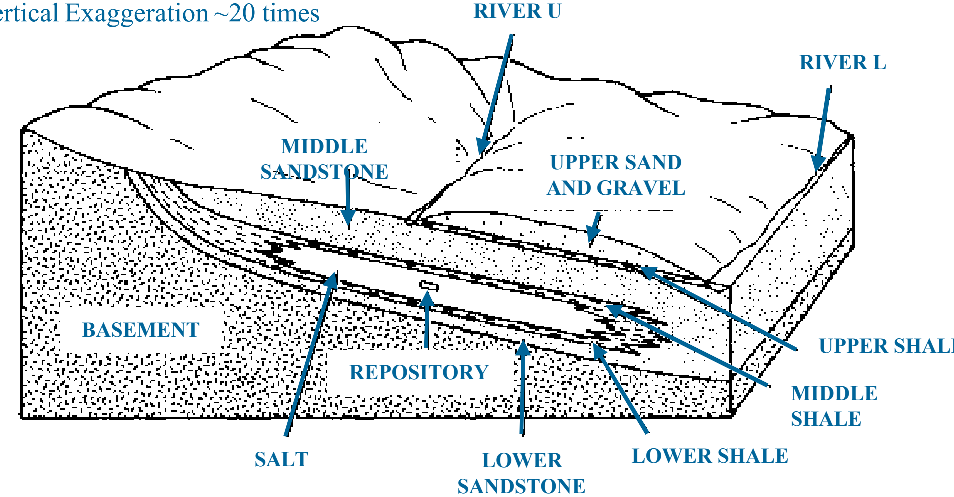
- Identified the need for a total nested (i.e., coupled) set of codes, allowing iterative deterministic and probabilistic calculations
- Demonstrated how to use sensitivity analyses to identify parameters for future study
- Identified the need for defining and including low probability events
- Demonstrated the use of Latin Hypercube Sampling (LHS) to optimize the number of calculations



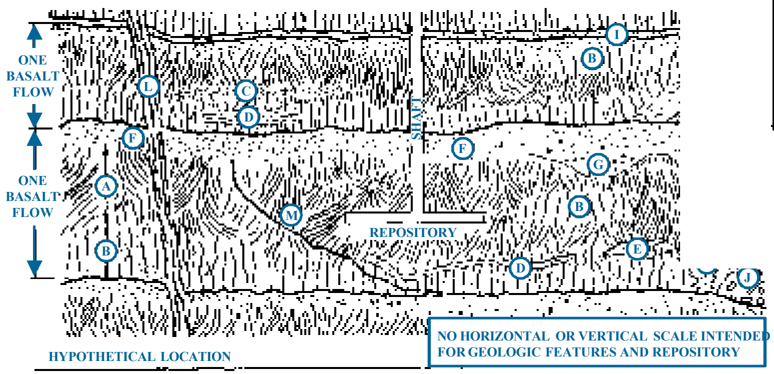
EARLY DEVELOPMENT AND IMPLEMENTATION FOR NRC

- **Generic HLW Repository in Bedded Salt**

Reference Site
Vertical Exaggeration ~20 times



- **Generic HLW Repository in Basalt**



FLOW INTERIOR DISCONTINUITIES

A
NTABLATURE JOINTS
B
OLONNADE JOINTS
C
ESICULAR ZONE
D
ATY ZONE
E
OCAL FRACTURED ZONE

FLOW CONTACT

F FLOW TOP
G LOCAL THICKENING OF FLOW-TOP BRECCIA
E
H FLOW TERMINATION
I SEDIMENTARY INTERBED
C J PILLOW BRECCIA
K SPIRACLE OR SPIRACLE-LIKE FEATURE
V
PL
L

BEDROCK STRUCTURAL DISCONTINUITIES

L FAULT OR FRACTURE ZONE, HINGE OF FOLD, OR SHEAR ZONE
M LOCALIZED TECTONIC FRACTURE

Hypothetical Composite Cross Section in a Layered Basalt Sequence

Evolution of Performance Assessment

- Probabilistic methodology required
  - Uncertainties too great for a deterministic analysis
- Multiple iterations of PA methodology required
  - As each iteration is completed, compare estimated performance measures to the requirements and stop when requirements have been met (and analyses are sufficiently mature)
  - WIPP PAs: 1989 (demonstration), 1990 (first full PA), 1991, 1992, 1994 (Systems Prioritization Method, SPM); 1996 (CCA), 2004 (first recertification), 2009 (second recertification)
  - YM TSPAs: 1991 (demonstration), 1993 (first full PA), 1995; 1998 (Viability Assessment); 2000-2001 (Site Recommendation); 2008 (LA– Authorization to Construct YM repository)
- PA provides a framework for organizing relevant data and information
  - Captures data and information from multiple sources; organizes it in a logical manner and uses it to support decision making, explicitly taking into consideration the uncertainties
  - Provides transparency and traceability to the analysis
  - All model calculations and decisions require retrievability, traceability and reproducibility; PA can analyze different components of a complex system in isolation and in conjunction with other components; intermediate results captured and results retrievable

Today's Discussion

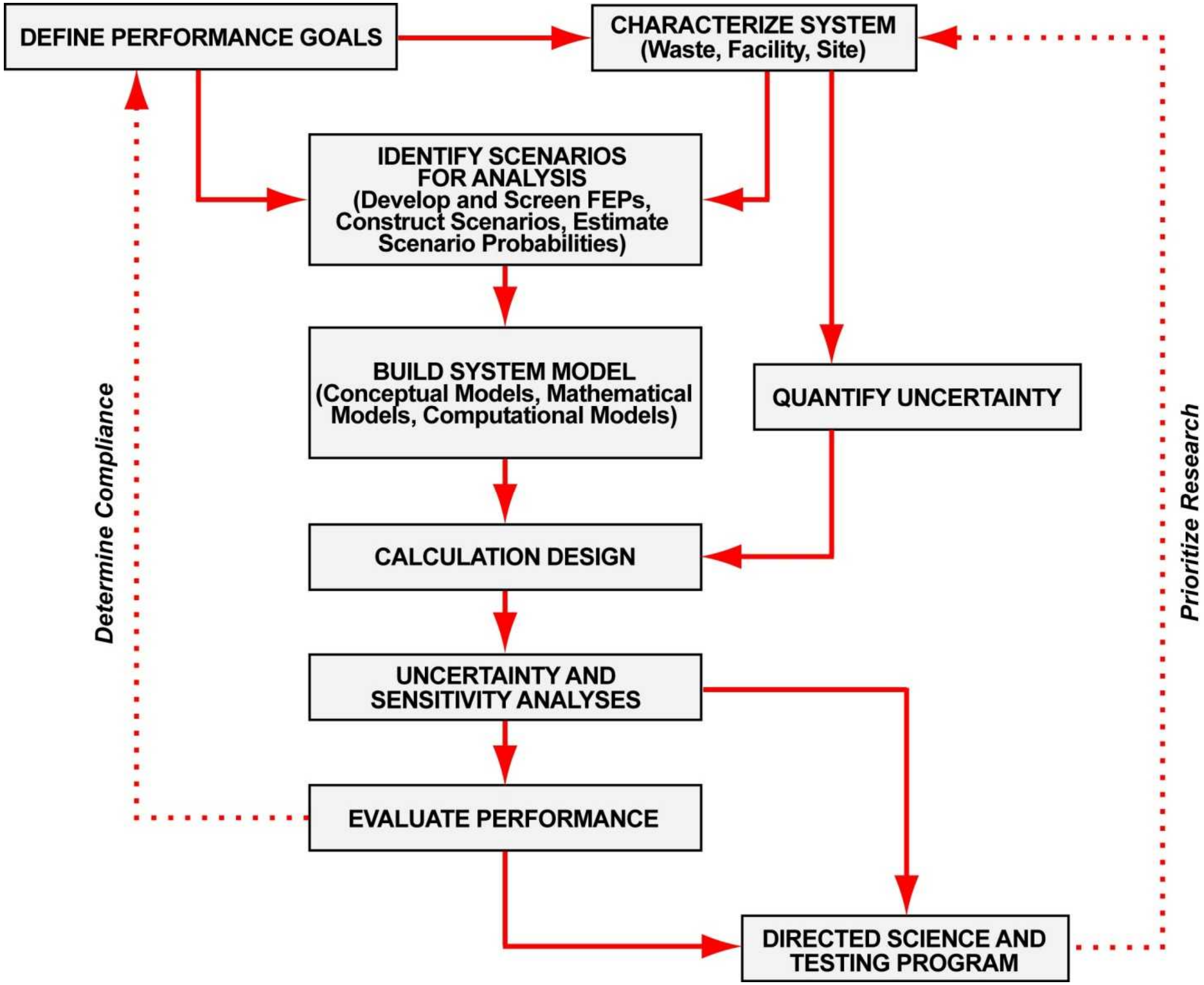
- Role of Performance Assessment in the Case for Safety
- Evolution of Performance Assessment

"ABCs" of Performance Assessment

- US Case Studies

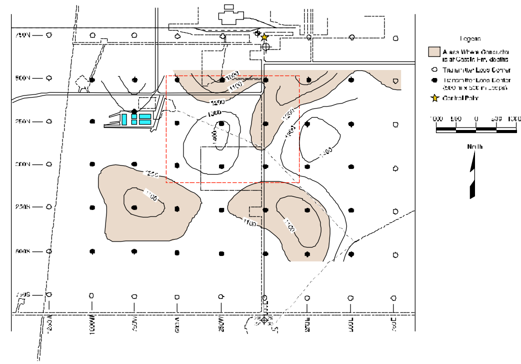
The "ABCs" of Performance Assessment

- PA answers three questions about a repository system:
  - **What can happen after permanent closure?**
  - **How likely is it to happen?**
  - **What can result if it does happen?**
- And one question about the analysis
  - **What level of confidence can be placed on the estimate? (uncertainty in analysis)**



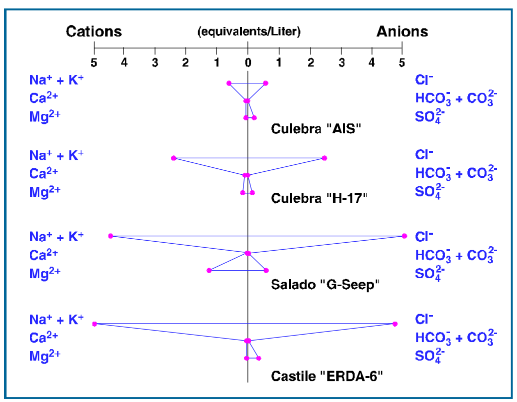
The "ABCs" of Performance Assessment

Geologic studies



Geophysical surveys

Hydrologic testing



Geochemical sampling and analysis

Geomechanical testing

Surface-based geologic drilling, coring, & geophysical logging

5.2-8.ppt

The "ABCs" of Performance Assessment

- A scenario is a generic description of the future evolution of the disposal system. Scenario uncertainty comes from different assumptions about the FEPs that may occur in the future and which FEPs and FEPs interactions are included in a particular scenario.
    - **All retained (screened-in) FEPs must be accounted for in PA in at least one scenario.**
    - **FEPs can be included by explicit modeling or by parameter assignment.**
    - **Expected FEPs are included in all scenarios**
      Creep closure
      Brine flow, gas generation
    - **Disruptive FEPs are included in disturbed scenarios.**
      Drilling, mining, brine pocket

The “ABCs” of Performance Assessment

- **Conceptual Models**
  - *a set of qualitative assumptions used to describe a system or subsystem.*

- Precisely define what needs to be modeled
- Identify what is known about the process being modeled
  - Site characterization data; Constraints; Necessary simplifying assumptions
- Develop a description of the process that is consistent with the known facts

- **Process Models**
  - *a number of parameters and relationships and solution of the mathematical model requires the assignment of particular values to the parameters.*

- Translate the description into a set of mathematical equations
- Identify input parameters that need to be assigned numerical values
- If the equations cannot be solved simply with analytical techniques, it may be necessary to implement numerical methods to solve the equations; Example: Finite difference or finite element methods

- **Computer Models**
  - *Integrated suite if codes, with parameter values*

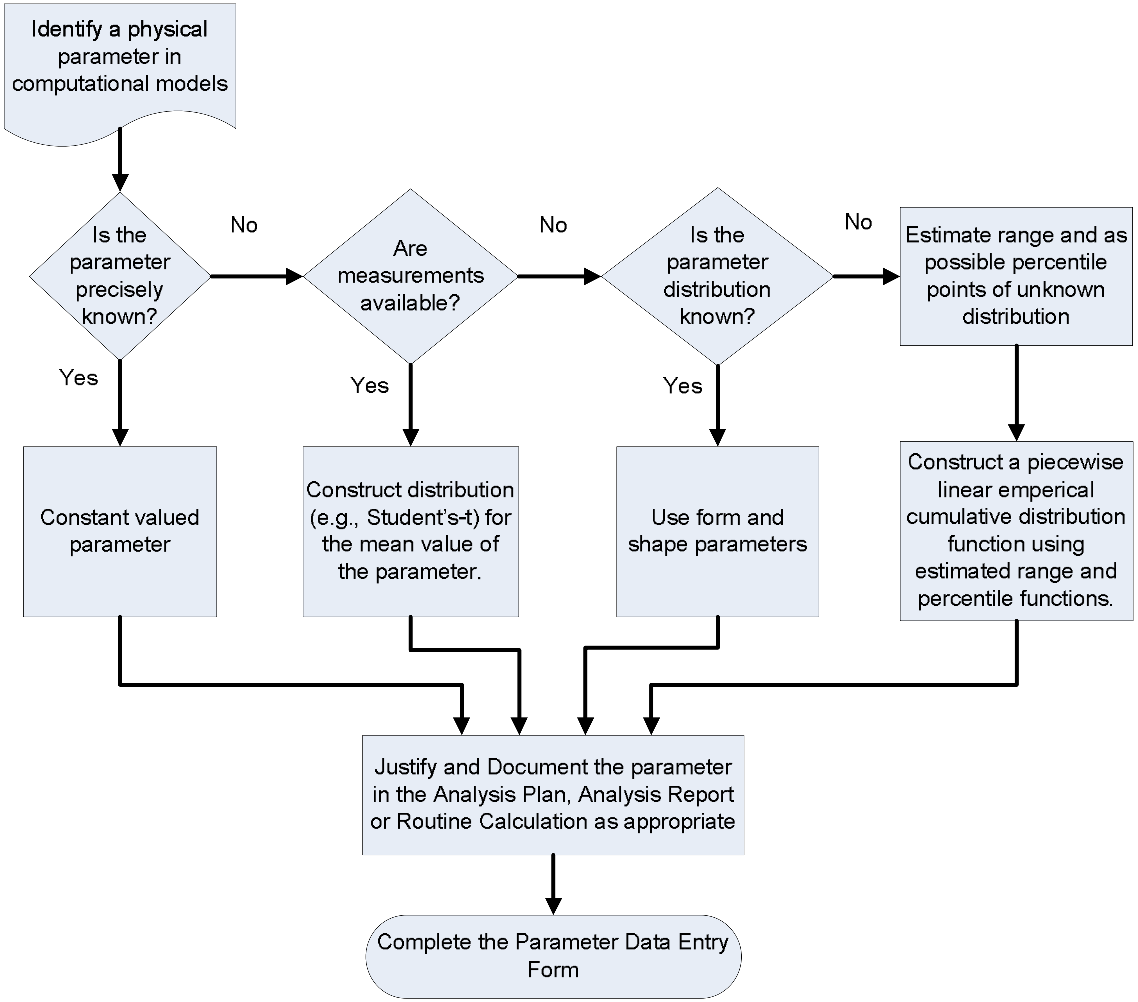
- Code development, i.e., implement the numerical methods into a computer code
- Code Testing-
  - Verification: ensure accuracy of the code
  - Validation: compare code predictions to “real life”data
- Sensitivity analysis and parameter refinement

The “ABCs” of Performance Assessment

- Moving from Deterministic to Probabilistic
  - Given all of the sources of uncertainty, it would be difficult (if not impossible) to put forth a credible deterministic prediction of the future performance of the repository
  - The first step in developing the probabilistic PA framework is identifying what types of uncertainties will be included
- Three principal types of uncertainty related to the stages of the PA development process
  - Scenario
    - *Stochastic (aleatory) uncertainty arises from a lack of knowledge about future events. The sequence of future events cannot be known. Example: Timing of future drilling events*
  - Conceptual Model
    - *uncertainty about the conceptual model chosen. Example: dual porosity model versus multi-rate transport model; equilibrium model versus kinetic model.*
  - Parameter
    - *Subjective (epistemic) uncertainty arises from a lack of knowledge about parameters assumed to have fixed values within the computational implementation of a PA. Examples: Permeability, Porosity.*

Database Parameterization

- Parameters are used in the modeling and to capture uncertainty
- Development of parameters is a process
  - Needs qualification from sources
  - Quality Assurance procedures help insure parameter integrity
- Parameter database
  - Tracks parameter values
  - Insures consistency between analyses



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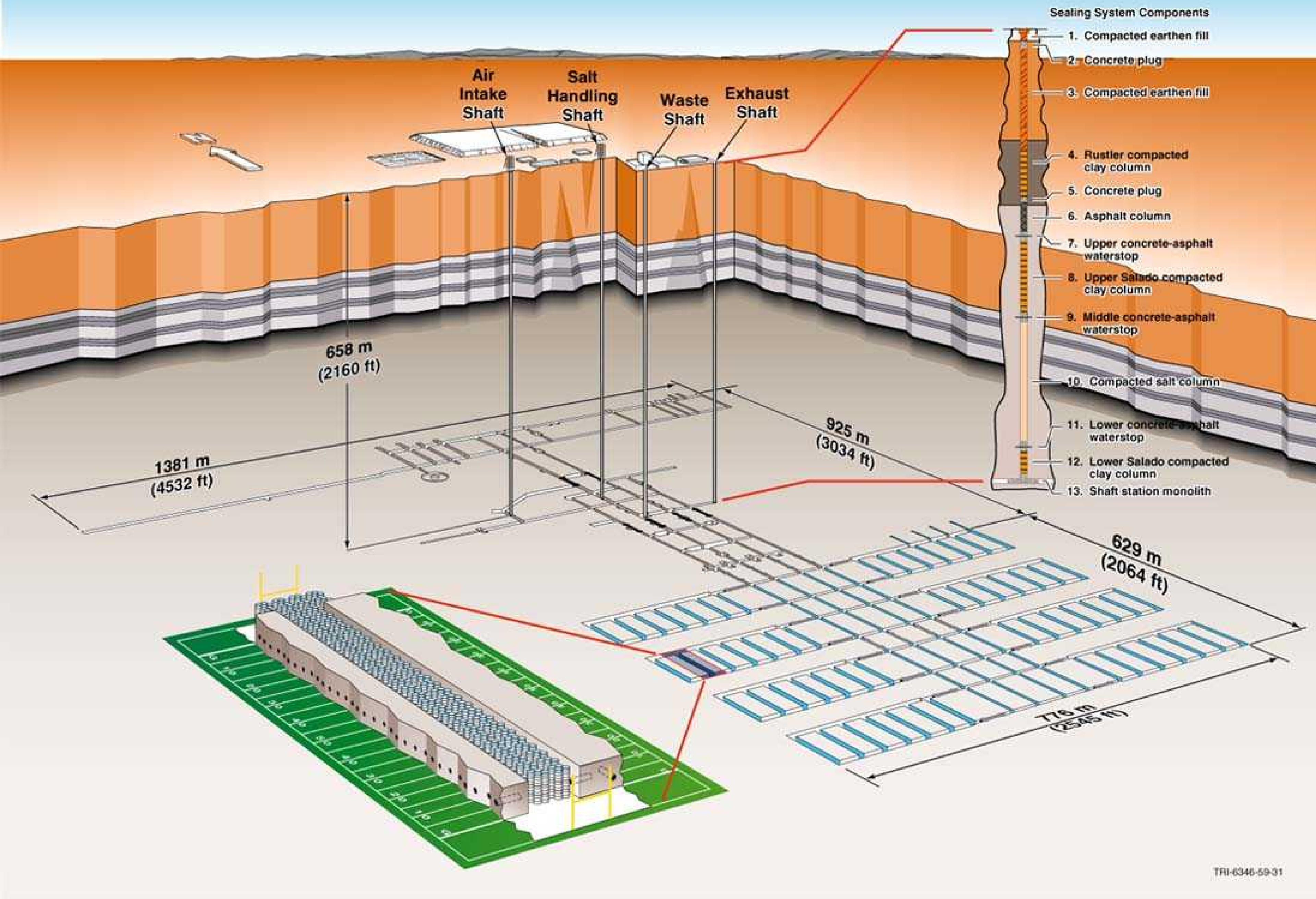
WIPP Layout

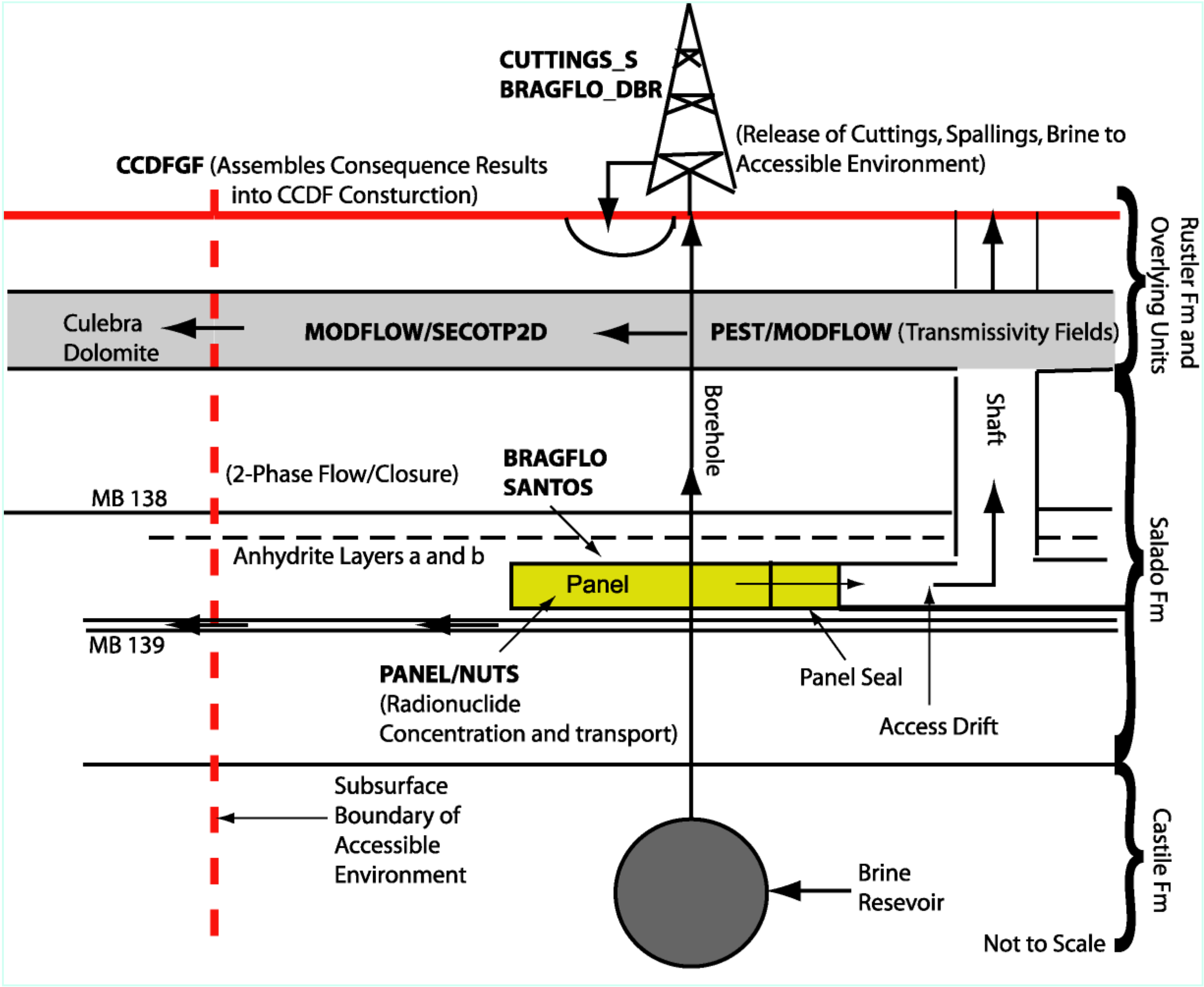


Sealing System Components
1. Compacted earthen fill
2. Concrete plug
3. Compacted earthen fill
4. Rustler compacted clay column
5. Concrete plug
6. Asphalt column
7. Upper concrete-asphalt waterstop
8. Upper Salado compacted clay column
9. Middle concrete-asphalt waterstop
10. Compacted salt column
11. Lower concrete-asphalt waterstop
12. Lower Salado compacted clay column
13. Shaft station monolith
Air Intake Shaft
Salt Handling Shaft
Waste Shaft
Exhaust Shaft
658 m
(2160 ft)
1381 m
(4532 ft)
925 m
(3034 ft)
629 m
(2064 ft)
776 m
(2545 ft)
TRI-6346-59-31

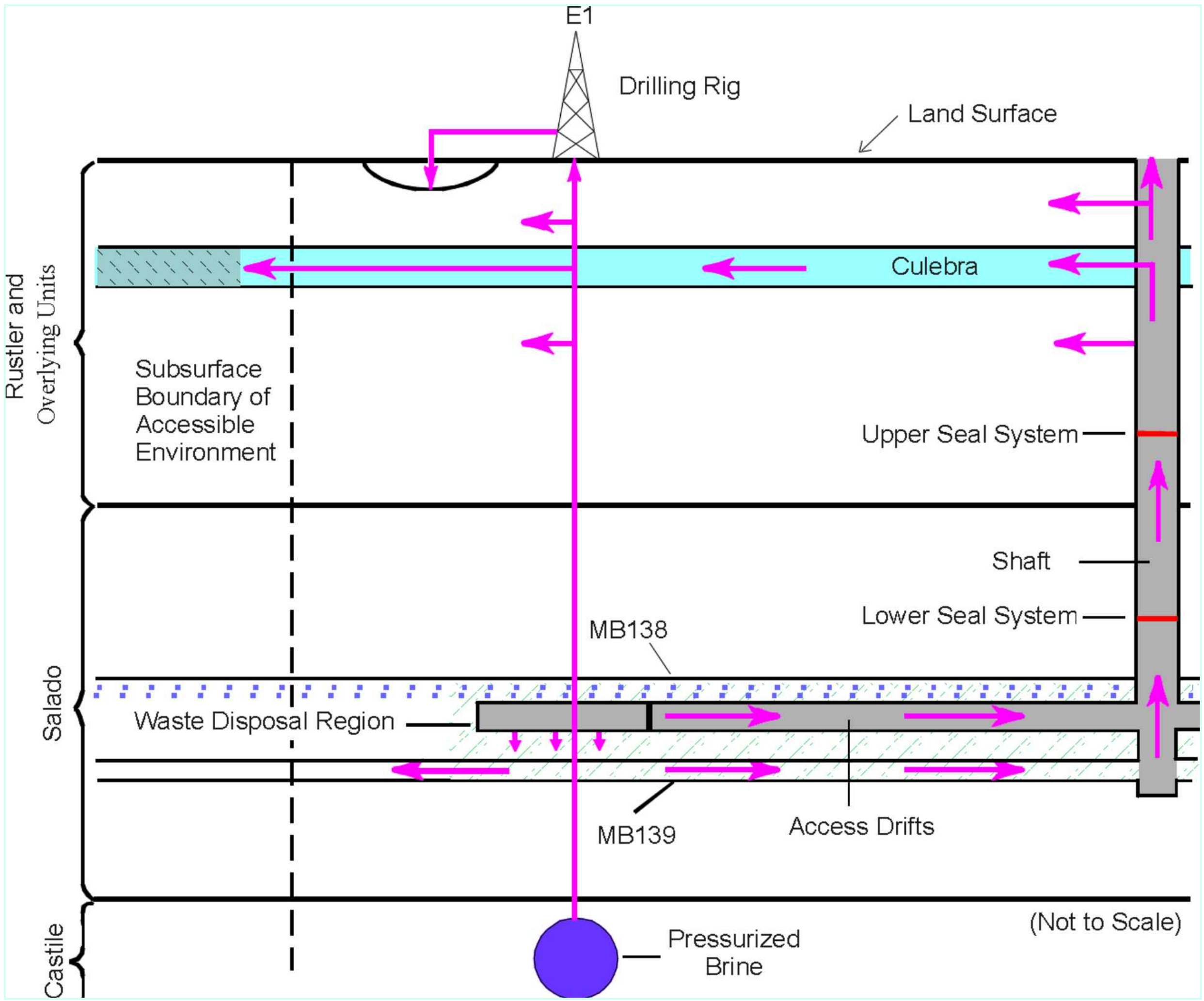
WIPP Features, Events, & Processes

- Features, events, and processes (FEPs) considered to be potentially important to the disposal system are identified
- FEPs are used as a tool for determining what phenomena and components of the disposal system can and should be dealt with in PA calculations
- FEPs are screened according to:
  - Probability: If a FEP has a probability of occurring less than 10^{-4} in 10,000 years it does not have to be included in PA (e.g., meteorite impact)
  - Consequence: if a FEP is beneficial to performance or has insignificant consequence (e.g., distribution of cumulative releases unchanged by omission)
  - Regulation: Certain FEPs are either screened in or out by regulation (e.g., mining, resource extraction following drilling)

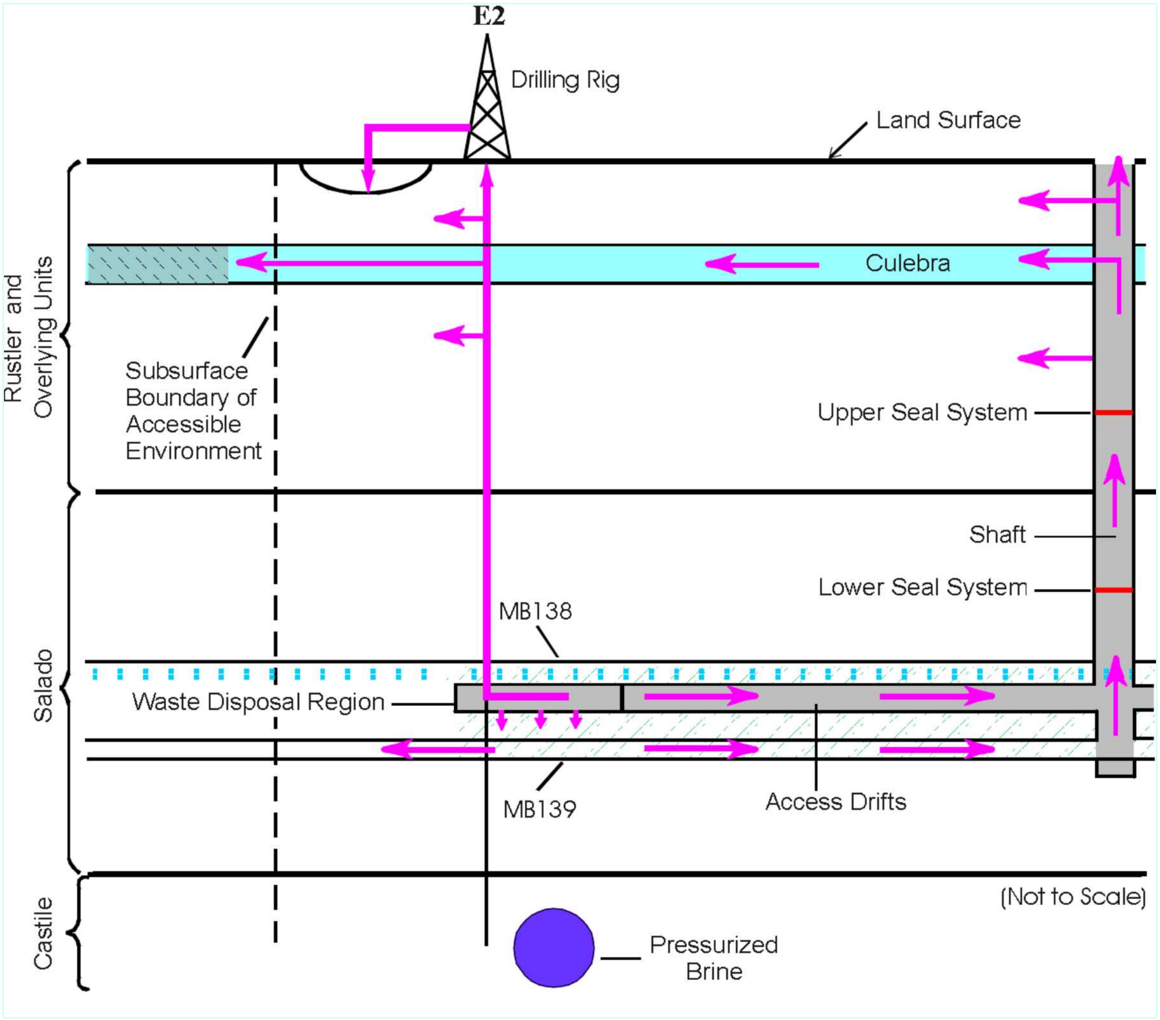
WIPP Release Pathways



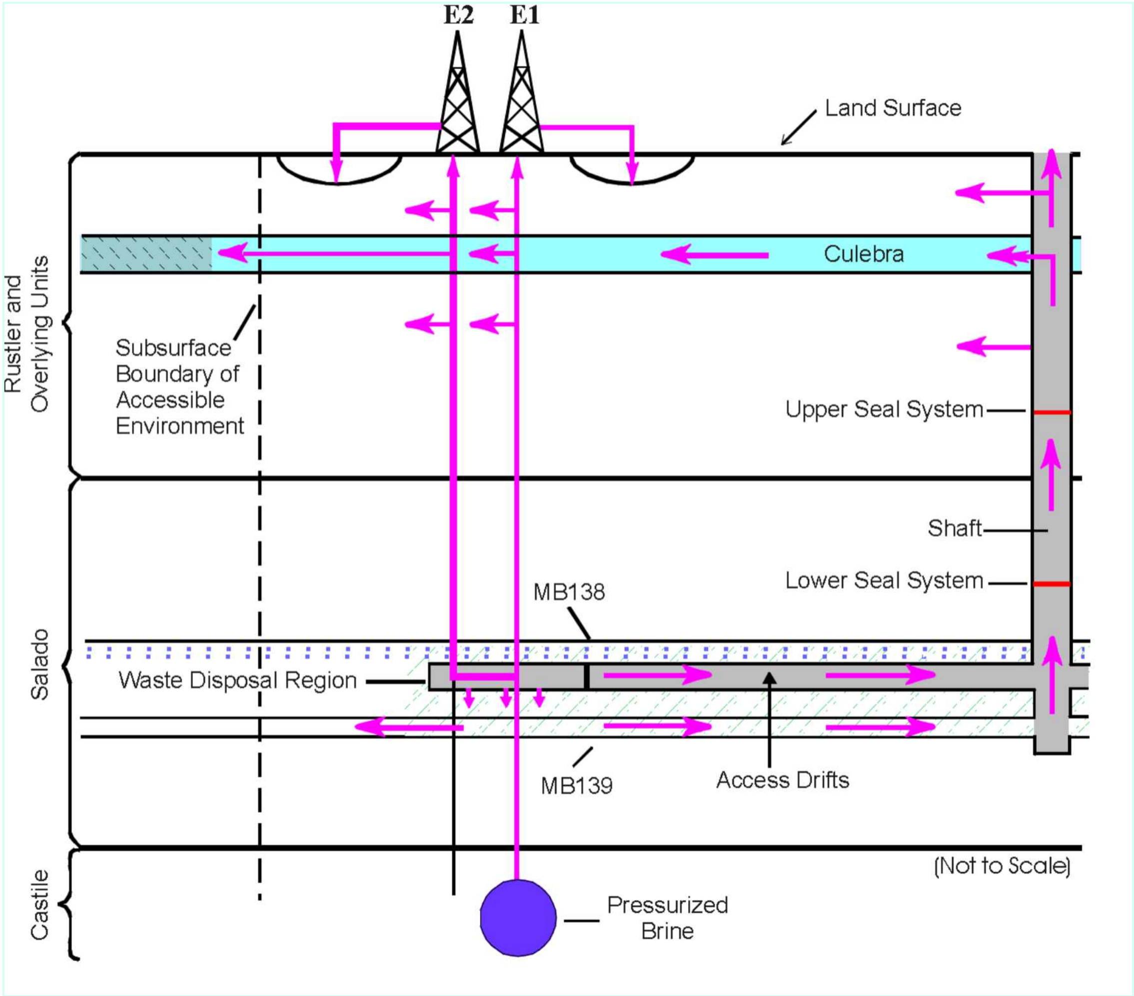
E1 Drilling Scenario



E2 Drilling Scenario



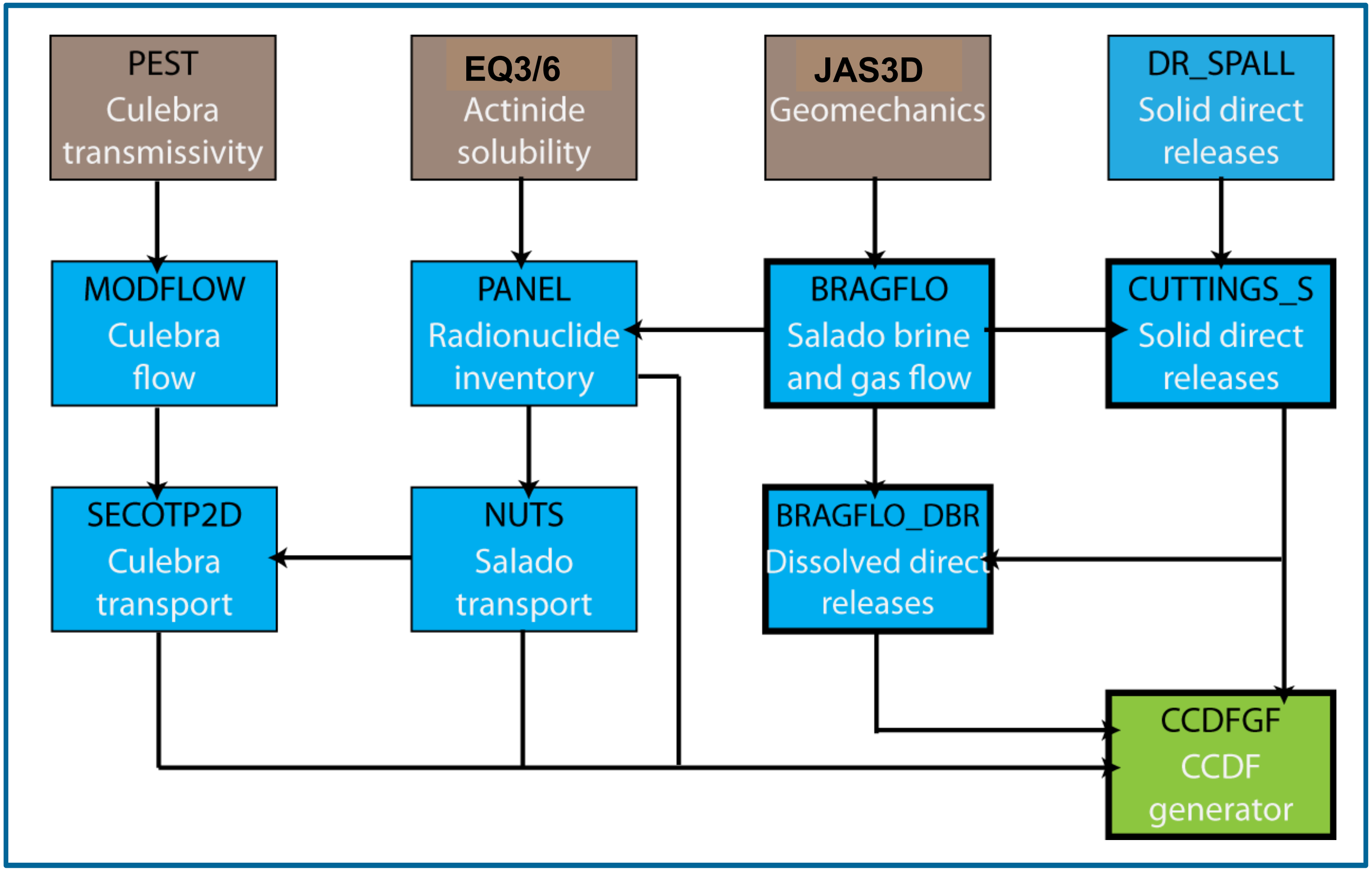
E1/E2 Drilling Scenario



WIPP PA Models

- 24 WIPP PA Conceptual Models
  Developed from FEPs, characterization, etc...
- Conceptual models are generally implemented in process models.
- Process models simulate distinct processes or groups of processes such as:
  Flow of brine and gas in the subsurface
  Radionuclide transport in the subsurface
  Gas generation
  Flow of brine and solids up a borehole
  Permeability enhancement due to fracturing
  Room closure
  Solid extraction by drilling

WIPP PA Modeling Codes



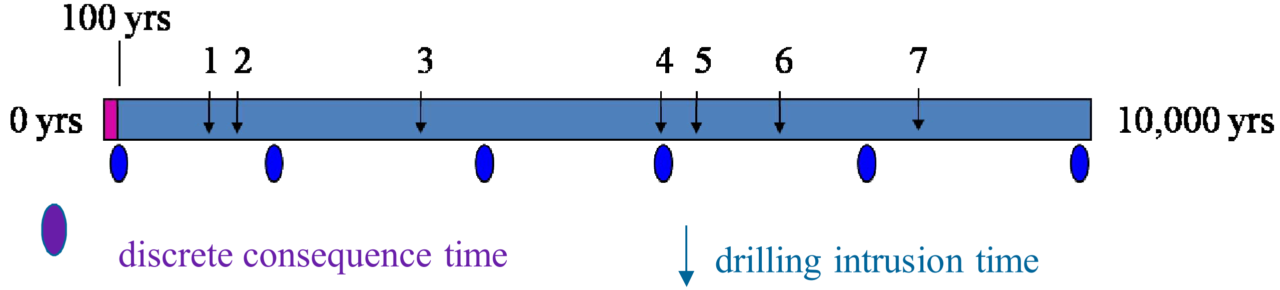
Dealing with Subjective Uncertainty

- Latin Hypercube sampling (LHS) is used to define 100 sets of uncertain parameters
- One realization of the sampled parameters is called a "vector"
- The group of 100 vectors is called a "replicate"
  - Results from all 100 vectors combined to determine mean releases (and percentiles).
  - The replicate essentially covers the full range of all the uncertain parameter distributions
- LHS minimizes the correlation between parameters unless directed otherwise
- Three replicates are run to demonstrate statistical equivalence

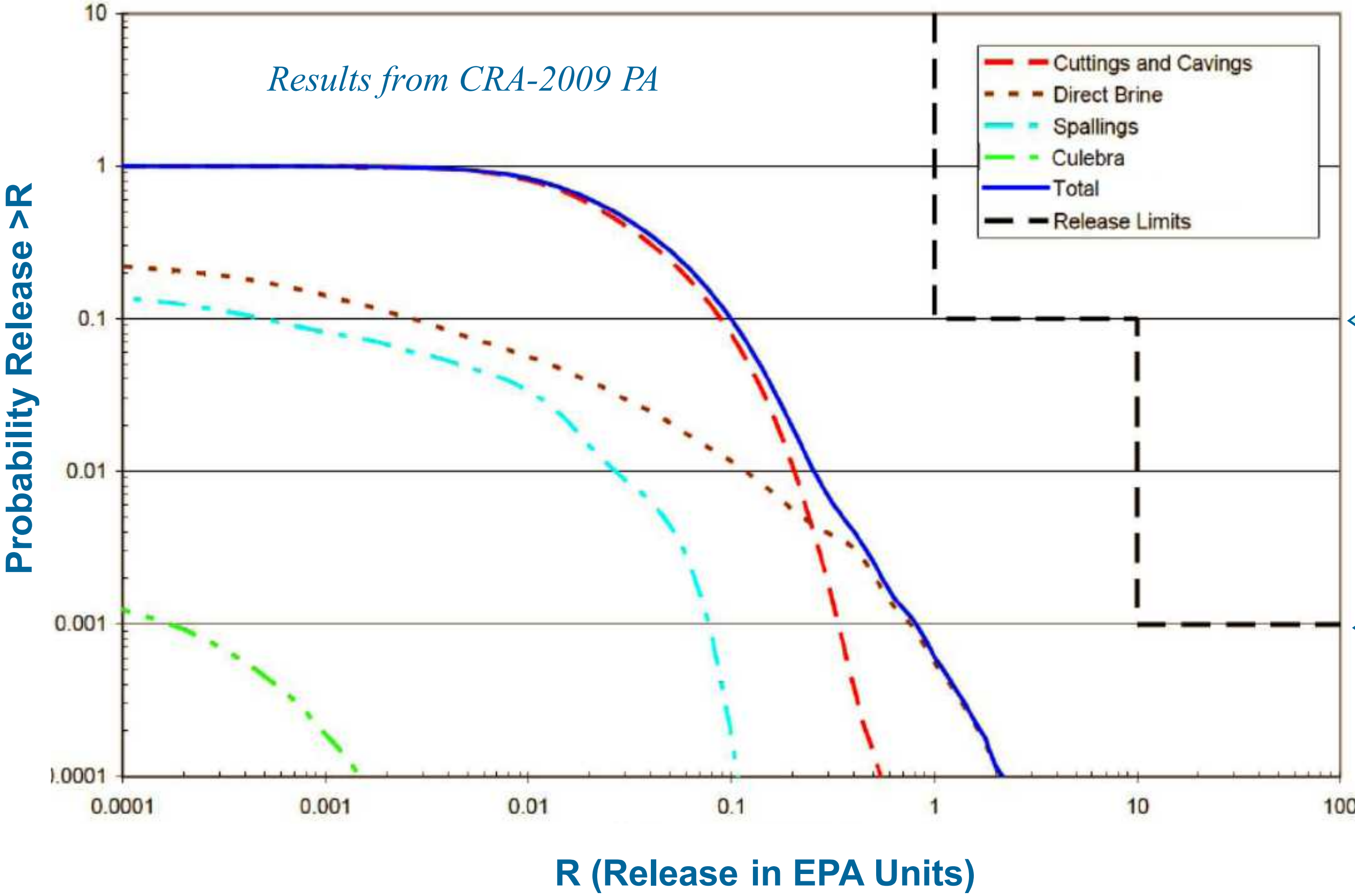
Dealing with Stochastic Uncertainty

WIPP PA treats stochastic uncertainty through Monte Carlo sampling on possible futures

- 10,000 futures evaluated for each vector to assign a probability to releases
  - A future is the cumulative release from one possible sequence of events from 0 to 10,000 years
  - Each future consists of a series of randomly occurring drilling intrusions
  - The consequences of drilling intrusions are calculated by interpolating between consequences at discrete times
  - Order statistics used to generate complementary cumulative distribution function (CCDF)



Mean CCDF by Component



CCDF is measure of compliance

Less than 1 chance in 10 of exceeding 1 EPA unit

Less than 1 chance in 1000 of exceeding 10 EPA units

TSPA-LA Scenarios

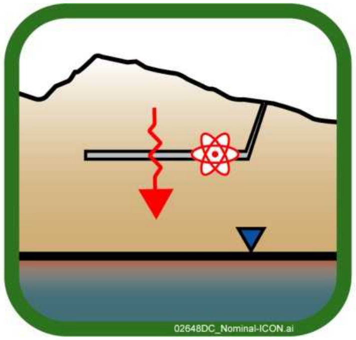
Four scenario classes divided into seven modeling cases

Nominal Scenario Class

- **Nominal Modeling Case** (included with Seismic Ground Motion for 1,000,000-yr analyses)

Early Failure Scenario Class

- Waste Package Modeling Case
- Drip Shield Modeling Case

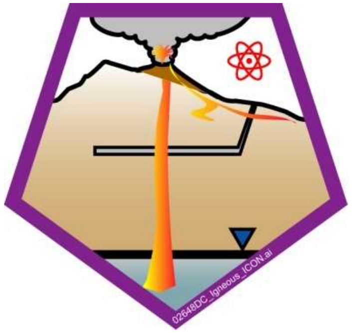


Seismic Scenario Class

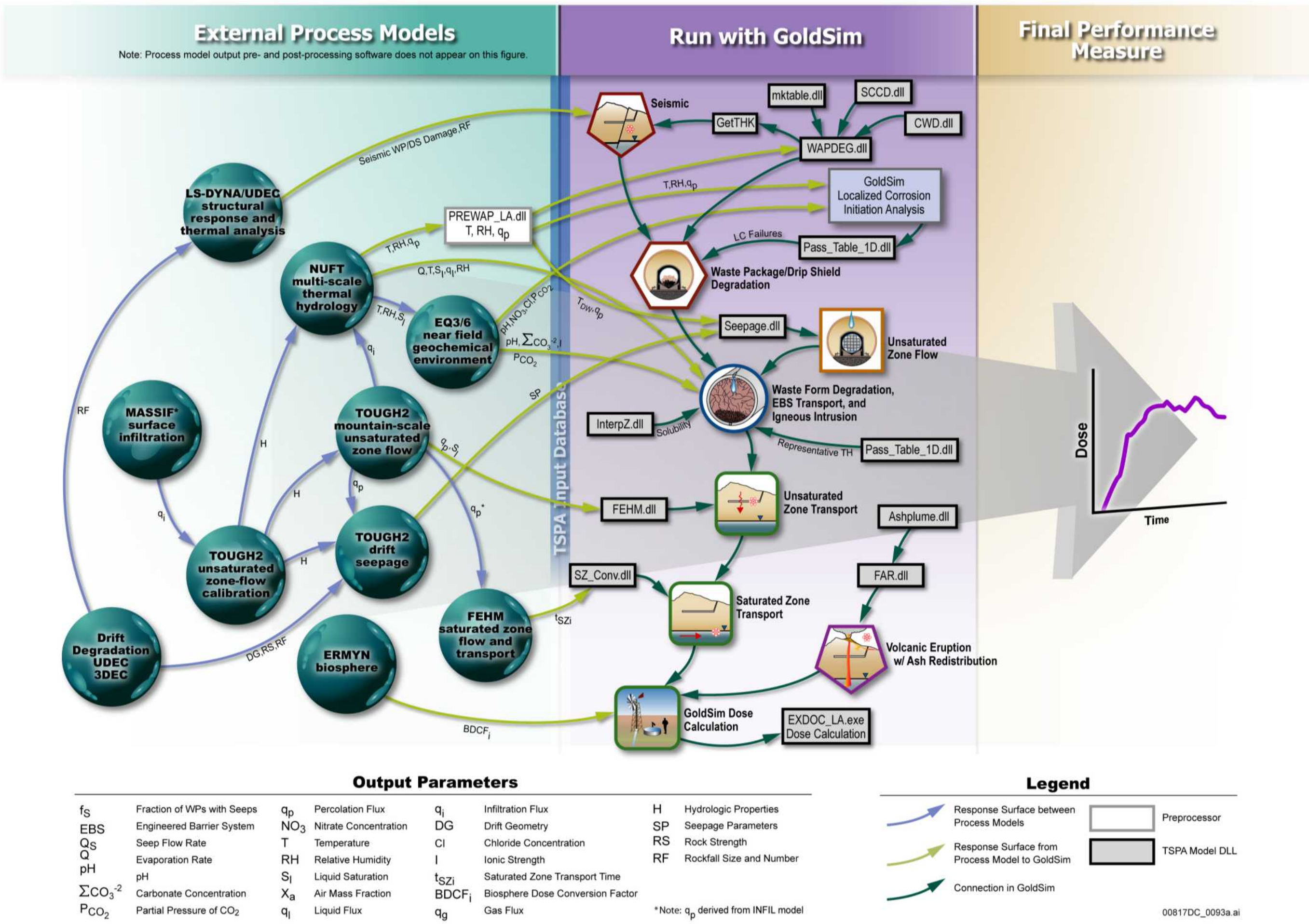
- Ground Motion Modeling Case
- Fault Displacement Modeling Case

Igneous Scenario Class

- Intrusion Modeling Case
- Eruption Modeling Case



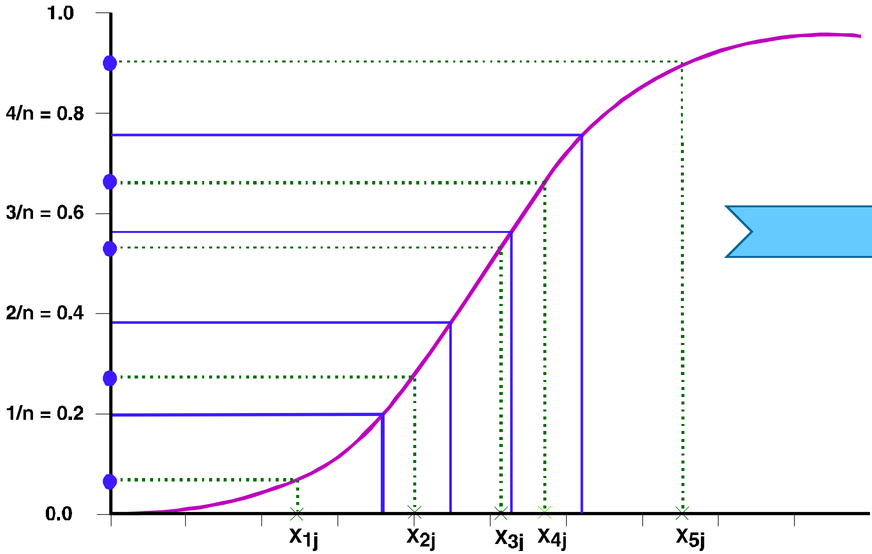
TSPA Architecture

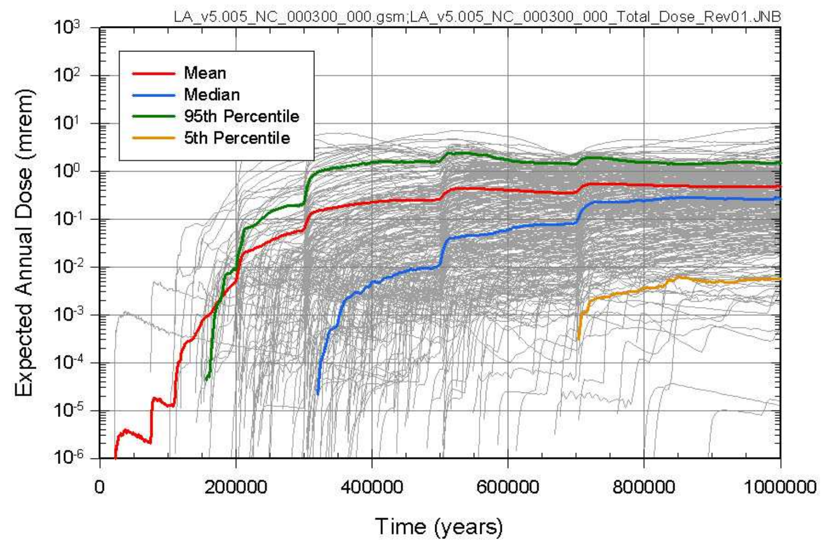


Uncertainty in YM TSPA

Epistemic uncertainty incorporated through Latin hypercube sampling of cumulative distribution functions and Monte Carlo simulation with multiple realizations

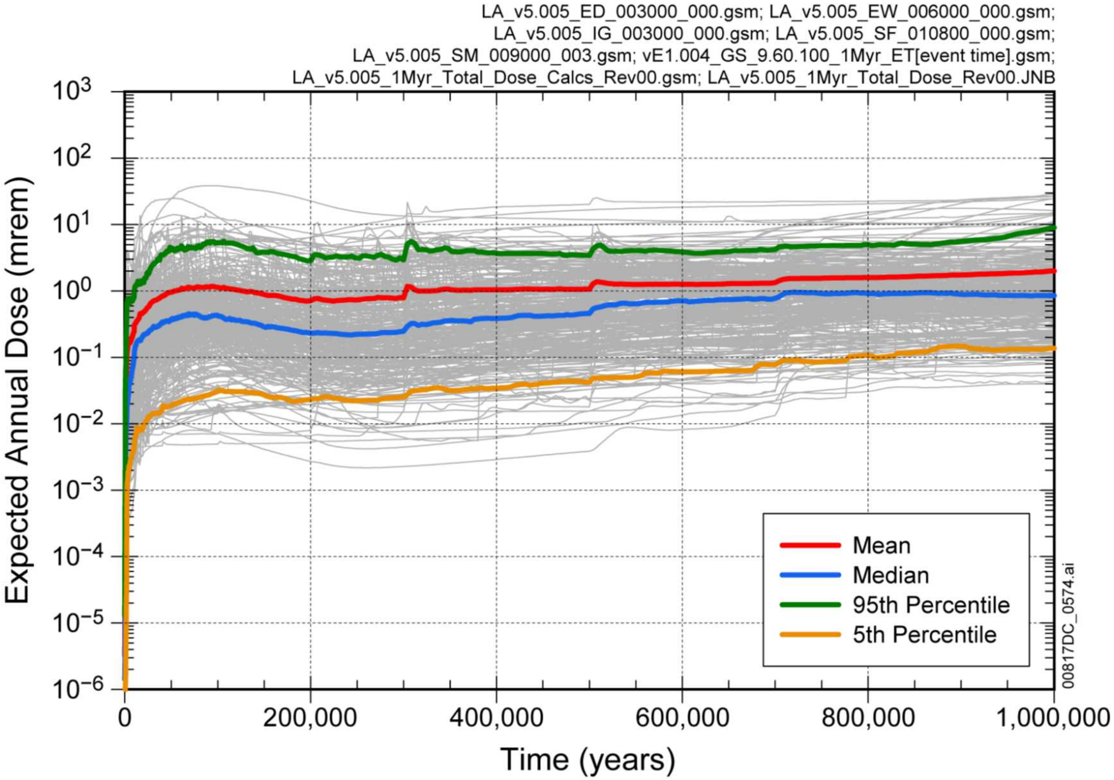
(approx. 400 uncertain epistemic parameters in TSPA-LA)





Aleatory uncertainty incorporated through the design of the analysis

TSPA Results



MDL-WIS-PA-000005 REV 00 AD 01, Figure 8.1-2[a]

1,000,000-yr Standard:

Mean annual dose no more than 1 mSv (100 mrem)

TSPA-LA estimated 1,000,000-yr maximum mean annual dose:

0.02 mSv (2.0 mrem)