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Overview of Performance Assessment for the Waste Isolation Pilot Plant

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Outline

- **Regulatory Structure and Release Limits**
- **Performance Assessment Methodology**
- **Performance Assessment into the Future**
- **Summary**

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Containment Requirements

40 CFR 191.13

(a) Disposal systems for spent nuclear fuel or high-level or transuranic radioactive wastes shall be designed to provide a reasonable expectation, based upon performance assessments, that the cumulative releases of radionuclides to the accessible environment for 10,000 years after disposal from all significant processes and events that may affect the disposal system shall:

(1) Have a likelihood of less than one chance in 10 of exceeding the quantities calculated according to Table 1 (Appendix A); and

(2) Have a likelihood of less than one chance in 1,000 of exceeding ten times the quantities calculated according to Table 1 (Appendix A).

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Table 1 (Appendix A to 40 CFR 191)

Radionuclide	Release Limit (L_i)(in curies) per 10^6 curies of TRU Waste
^{230}Th, ^{232}Th	10
^{241}Am, ^{243}Am, ^{14}C, ^{129}I, ^{237}Np, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{242}Pu, ^{226}Ra, ^{233}U, ^{234}U, ^{235}U, ^{236}U, ^{238}U, and other alpha-emitting radionuclide with a half-life greater than 20 years.	100
^{135}Cs, ^{137}Cs, ^{90}Sr, ^{126}Sn, and other radionuclide with a half-life greater than 20 years that does not emit alpha particles.	1,000
^{99}Tc	10,000

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Release Limits

Releases are normalized by radionuclide and by the total inventory

$$nR = \sum \frac{Q_i}{L_i}\left(\frac{1\times 10^6 \, curies}{C}\right)$$

nR = Normalized release in "EPA units"
Q_i = 10,000-year cumulative release (in curies) of radionuclide i
L_i = Release Limit for radionuclide i
C = the total transuranic inventory (in curies)

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PA Objectives

- **PA answers three questions about a repository system:**
  1. **What can happen after permanent closure?**
  2. **How likely is it to happen?**
  3. **What can result if it does happen?**

- **And one question about the analysis**
  1. **What level of confidence can be placed on the estimate? (uncertainty in analysis)**

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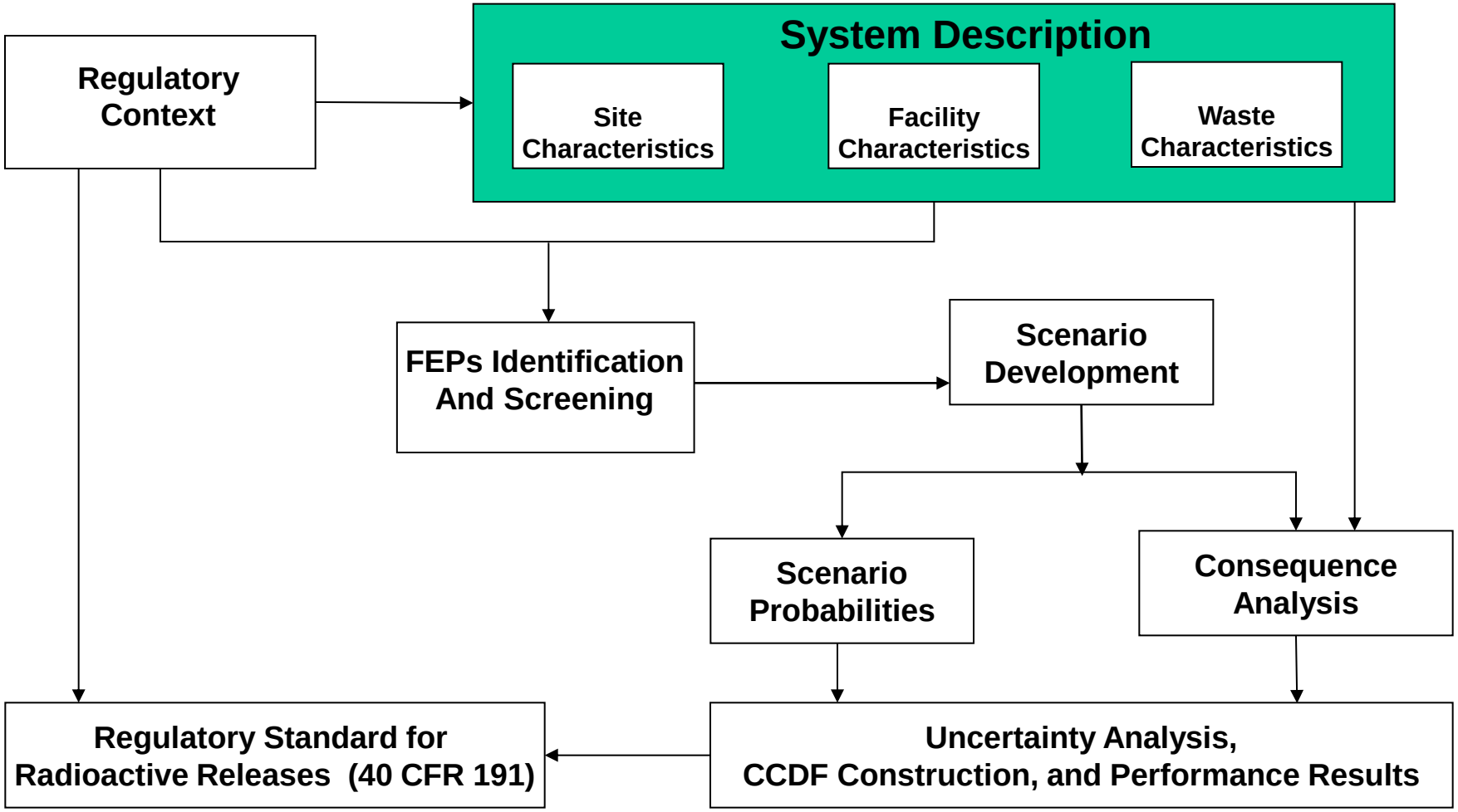
WIPP Performance Assessment Methodology



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Site Characterization & Repository Investigations

- **Site characterization information is necessary to define disposal system in WIPP models**
  - **Site characterization activities have mostly ceased, but we still conduct/need confirmatory information (e.g., regional hydrology)**

- **Repository investigations support the development of conceptual models in PA**
  - **Support DOE efficiency-driven changes (MgO reduction)**
  - **Supports improvement of existing models (iron/lead corrosion experiments, waste shear strength)**

Features, Events, and Processes

Features, events, and processes (FEPs) analysis determines what is to be considered in PA.

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, is not relevant to WIPP, or has a insignificant consequence to the disposal system, it does not have to be included in PA (e.g., sorption, lakes, oceans, tides, floods). *If a FEP is related to the WIPP disposal system and/or impacts the repository, it must be accounted for in PA (e.g., chemical effects of corrosion).***
- **Regulation: Certain FEPs are either screened in or out by regulation (e.g., mining, resource extraction following drilling).**

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24 WIPP Conceptual Models

- Disposal system geometry
- Culebra hydrogeology
- Repository fluid flow
- Salado
- Impure halite
- Salado interbeds
- Disturbed rock zone
- Actinide transport in Salado
- Units above the Salado
- Dissolved transport in Culebra
- Colloidal transport in Culebra
- Exploration boreholes
- Cuttings/Cavings
- Spallings
- Direct brine release
- Castile and brine reservoir
- Multiple intrusions
- Climate change
- Creep closure
- Shafts and shaft seals
- Gas generation
- Chemical conditions
- Dissolved actinide source term
- Colloidal actinide source term

FEP: *Chemical Effects of Corrosion* → Fe Corrosion Experiments

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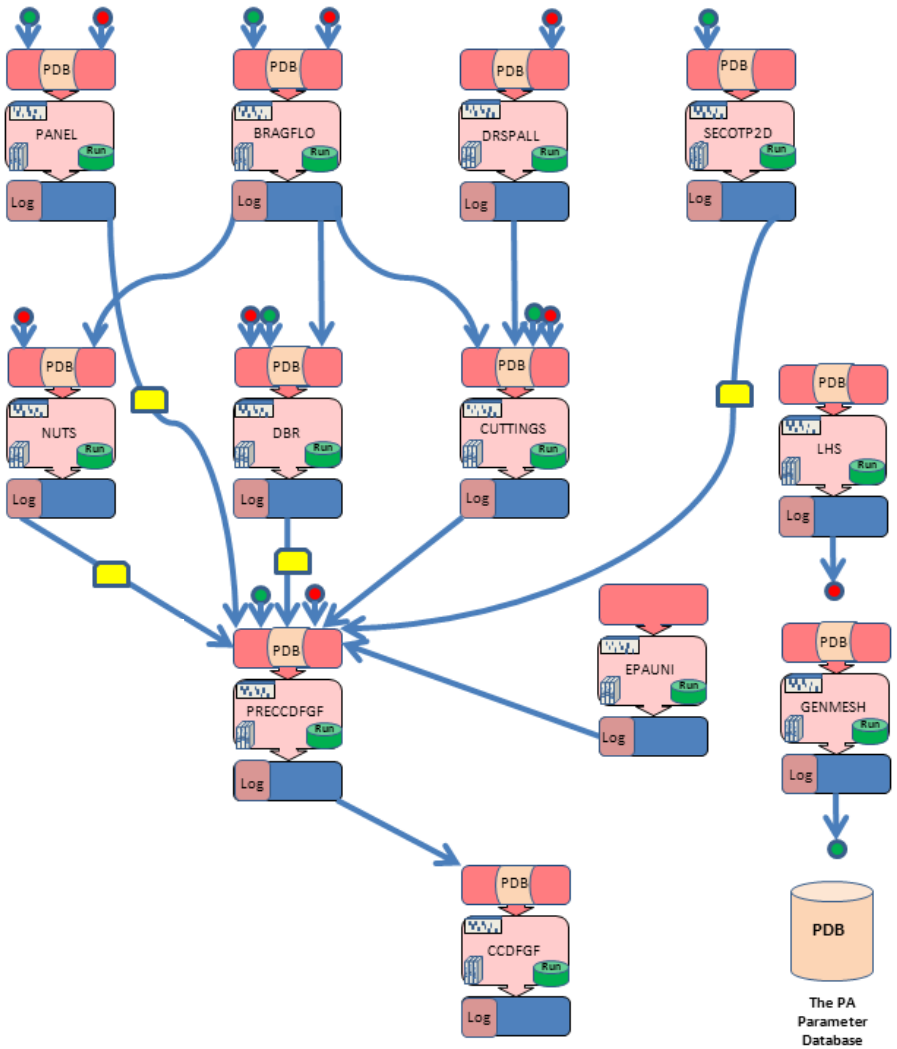
Process Models

- 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 Codes



WIPP Process Models are Implemented in a Suite of Numerical Codes

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Scenario Development

- 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

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Release Mechanisms

- **Direct Releases (occur during or immediately after drilling)**
  - **Cuttings (Solids removed due to drilling)**
  - **Cavings (Solids from borehole wall)**
  - **Spallings (Solids from pressure release)**
  - **Direct Brine Release (Brine from pressure release)**
- **Long-term Releases**
  - **Groundwater Transport in Culebra**

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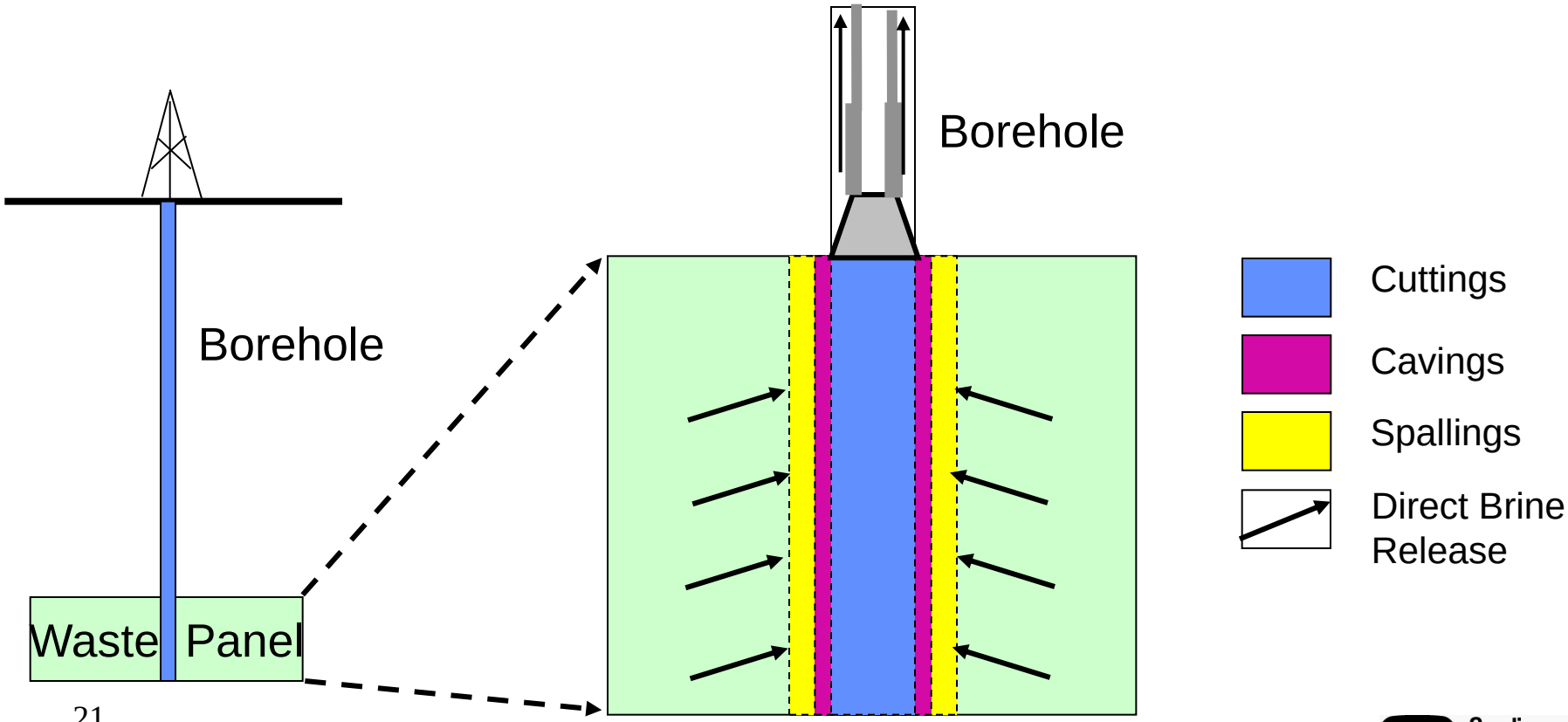
Direct Releases

Direct Releases Dominate Total Releases



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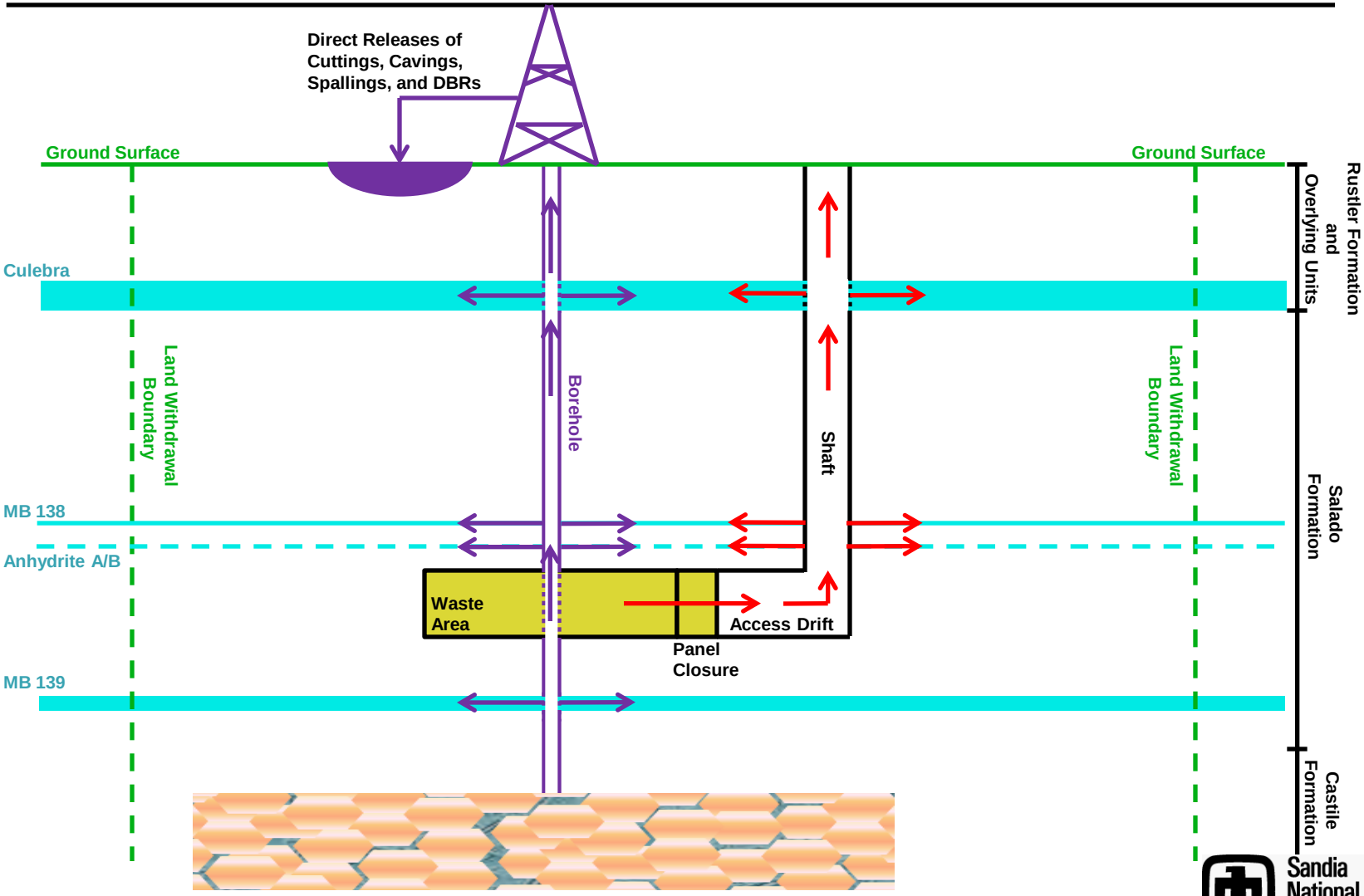
Release Pathways



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Epistemic Uncertainty

1. Epistemic Uncertainty
   - Arises from a lack of knowledge about parameters that have fixed, but unknown values within the computational implementation of a PA.
     - Examples: permeability, porosity, etc.

   - WIPP PA treats epistemic uncertainty in several ways:
     i. Make assumptions that over-estimate releases (conservative assumptions). *Example: Waste shear strength parameterization*
     ii. Sample certain parameter values from probability distributions that cover the range of uncertainty.

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Aleatory Uncertainty

2. Aleatory Uncertainty

- **Arises because the system can potentially behave in many different ways. The sequence of future events *cannot* be known.**
  - **Examples: Timing and location of future drilling events, when potash mining is completed, whether microbial gas generation can occur.**
- **WIPP PA treats aleatory uncertainty through Monte Carlo sampling on possible futures (sequences of events).**

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Complementary Cumulative Distribution Function (CCDF)

By regulation, PA results are presented as a distribution of CCDFs of releases.

- Process models are used to calculate repository behavior over a range of sampled parameter values to account for epistemic uncertainty.

- Random sequences of future events (e.g. intrusion times and locations) are generated to account for aleatory uncertainty.

- An individual CCDF summarizes the likelihood of release across all futures for one set of sampled parameter values.

- The CCDF curve is the metric of compliance.

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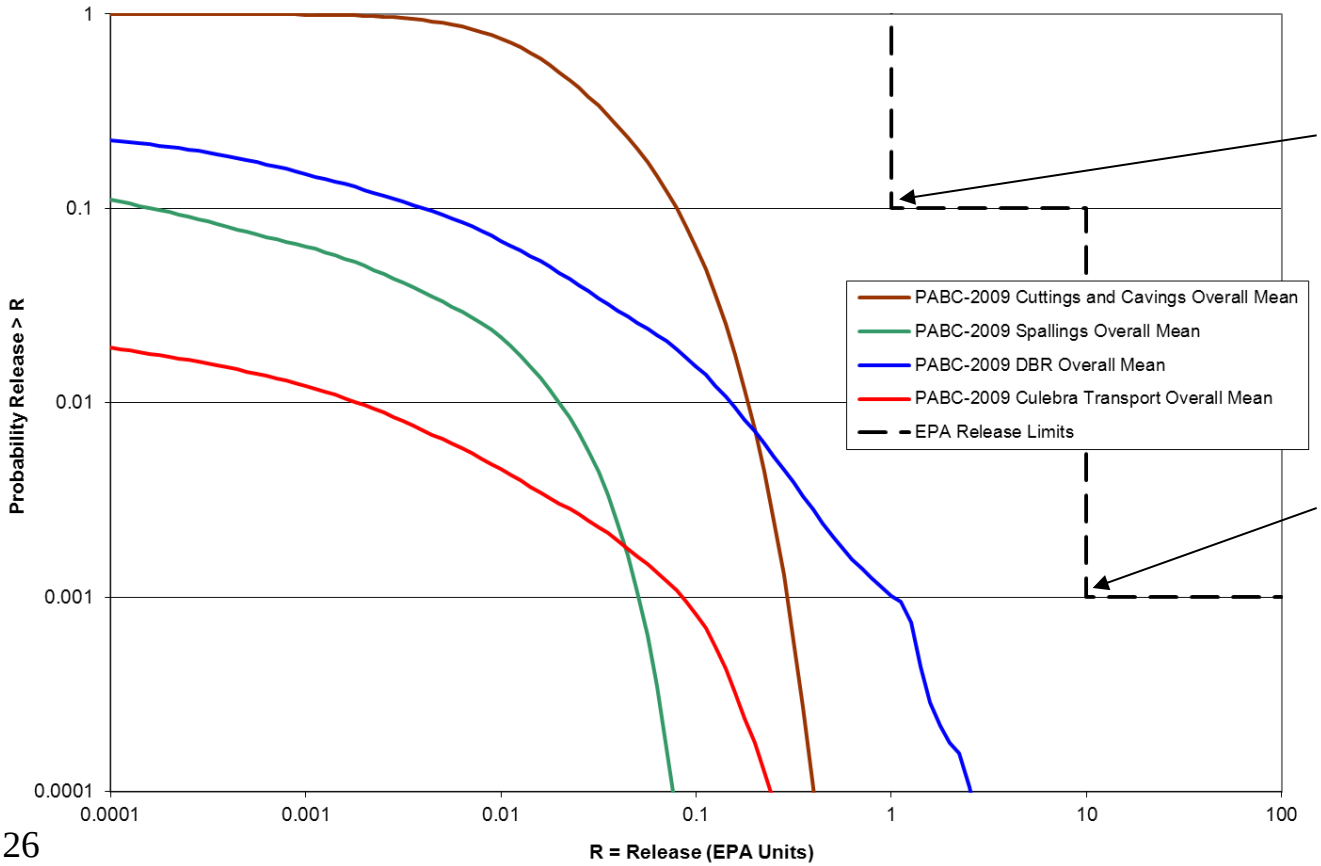
CCDF is a Measure of Compliance

Each Release Component is Quantified



Less than 1 chance in 10 of exceeding 1 EPA unit

Less than 1 chance in 1000 of exceeding 10 EPA units

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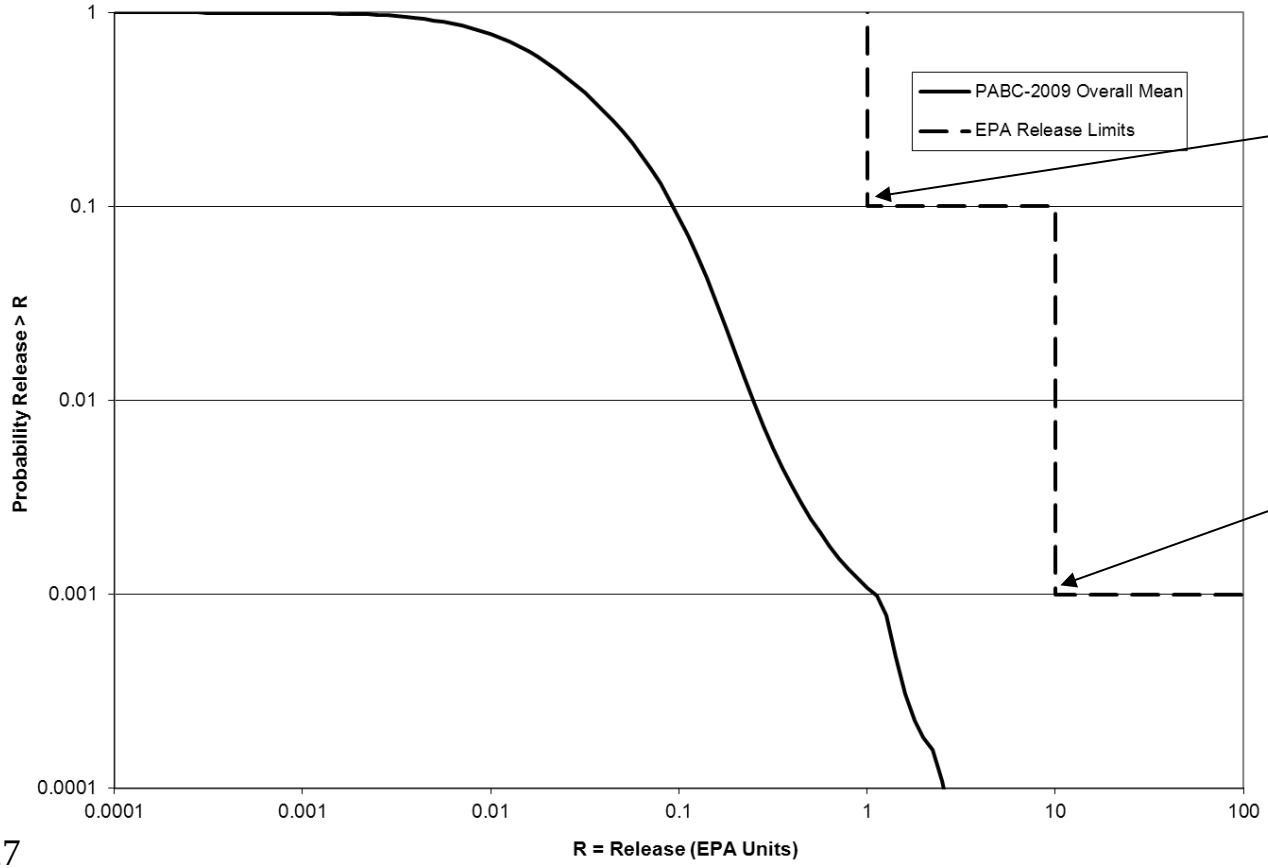
CCDF is a Measure of Compliance

Total Normalized Releases are Compared to Compliance Limits



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PA Migration

The current PA computing framework is done on a HP/Compaq Alpha Cluster with an OpenVMS OS.

- The Alpha/OpenVMS platform is very stable and has been successfully used in the WIPP compliance environment.

- Technical support of the hardware and OS is diminishing, and is becoming increasingly expensive.

- In order to sustain the PA capability into the future, the PA framework is being migrated to a UNIX (Solaris)/Intel based configuration → much faster calculation times.

- This is a slow effort and is being performed as time allows.

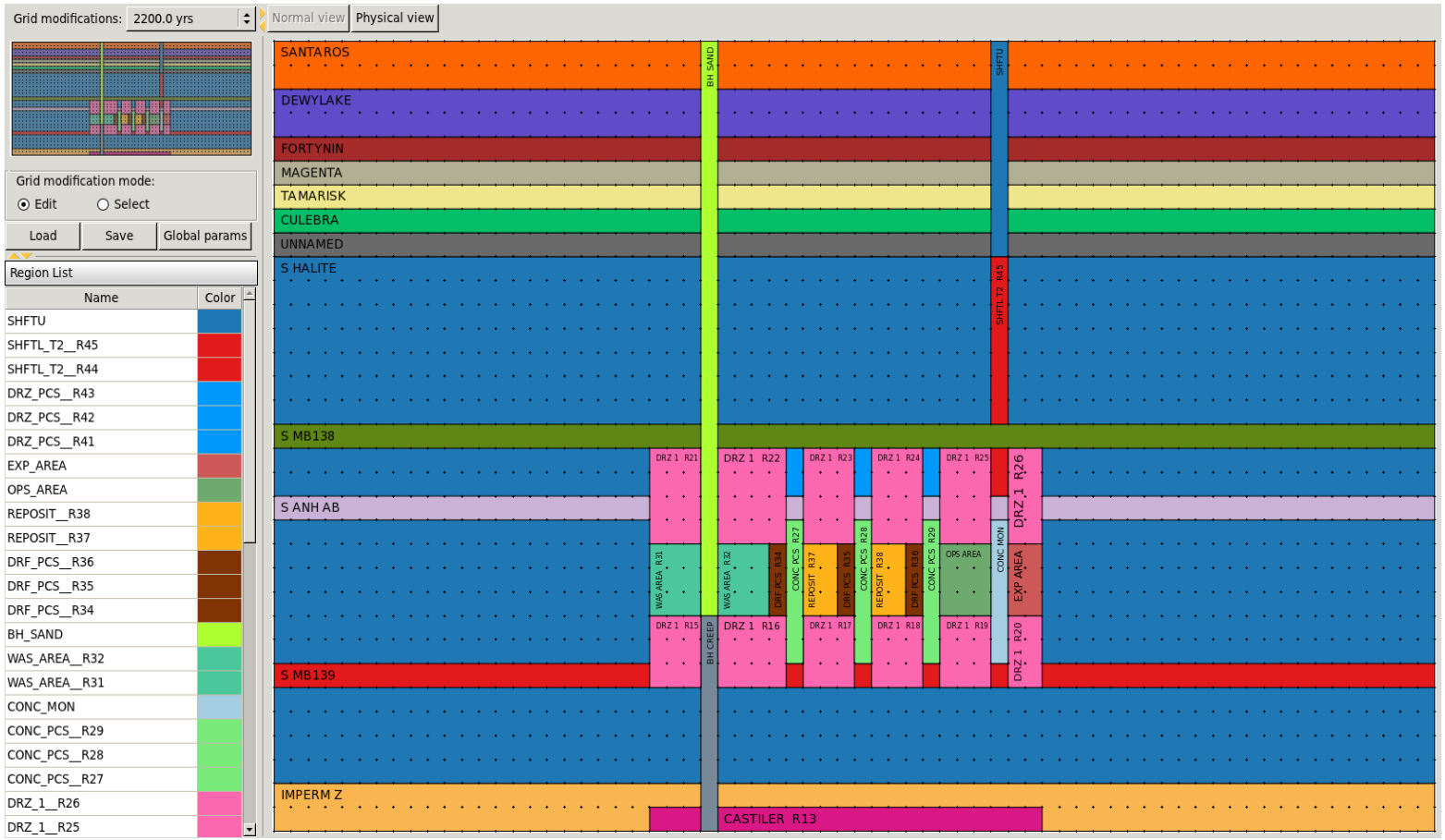
Dynamic PA Tool Development

Most of the software engineering undertaken to develop WIPP PA was done in the 1980s and 1990s.

- WIPP PA codes are “rigid” and make scoping calculations time-consuming and difficult. For example, grid changes must be hand-traced through extensive sets of input files to ensure correctness of calculated results.
- Incorporation of modern tools have the potential to make WIPP PA, and PA in general, much more flexible.
- Initial work has been done to investigate advantages gained by leveraging flexible modern tools for PA, with WIPP PA being used as a test case.

Flexible Grid Modification Tools

Repository Designer



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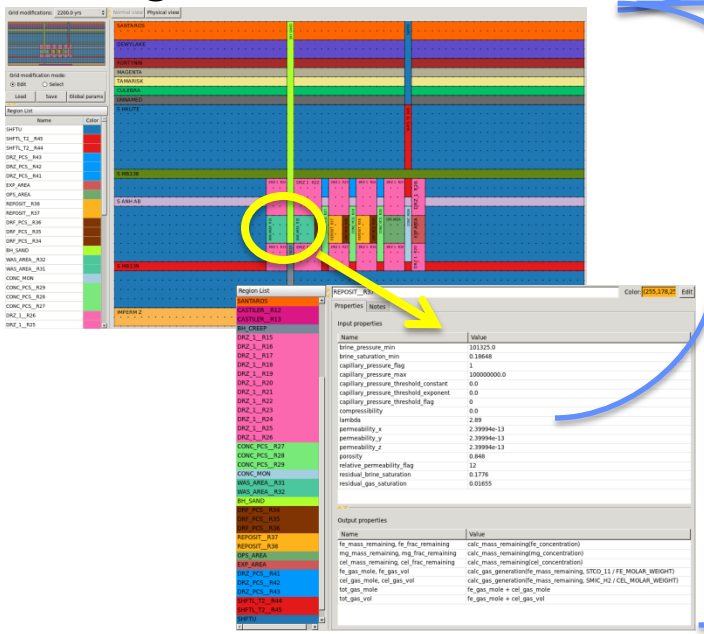
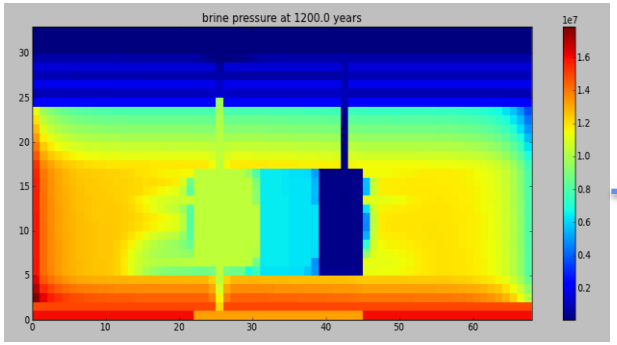
PA Control Center

One location for all configuration info:

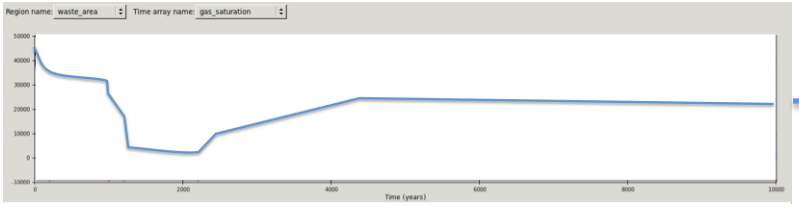


apps

Bragflo



(Algebra2)



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Summary

- WIPP Performance Assessment is a probabilistic framework to estimate releases to the accessible environment over 10,000 years.
- PA uses a collection of site-specific conceptual models, process models, and scenarios.
- PA explicitly includes both epistemic and aleatory uncertainty.
- CCDF for mean total releases is the measure of WIPP compliance with EPA release limits.
- PA continues to be refined and enhanced to ensure longevity into the future.

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Repository Flow

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Run Control

Steve Wagner

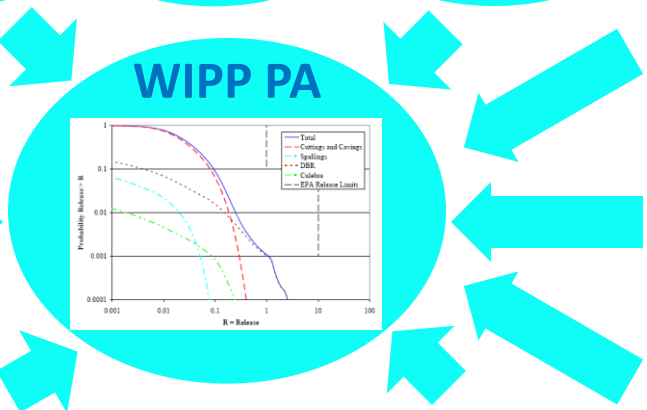
Compliance Monitoring

Je-Hun Jang

Geochemistry

Leslie Kirkes

Geochemistry Lab



Kevin Barnhart

Hydrology

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Geochemistry Modeling

Kris Kuhlman

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Rock Mechanics

Sean Dunagan

Waste Inventory

Courtney Herrick

Rock Mechanics

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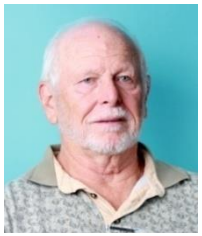
Aqueous Chemistry



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Radionuclide Transport

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