Performance Assessment Community of Practice Technical Exchange
July 13-14, 2009

Modeling the Performance of Engineered Systems for Closure and Near-Surface Disposal -

Overview and Focused Discussions

David S. Kosson
CRESP and Vanderbilt University

Tank Waste Corporate Board Meeting
July 29, 2009

Agenda

- Overview of DOE Performance Assessment Practices
- Focused Discussions
  - Role of PA Process in Risk Communication and Decisions
  - Modeling Improvements
  - PA Assumption Validation
  - Uncertainty Evaluation
  - Evolving EPA Developments
  - Related IAEA Activities
- Looking forward

PA CoP Tech Exchange - Overview

- Focus on predicting performance of engineered systems for near surface disposal (e.g., "source term")
- Included approaches and lessons learned from U.S. deep geologic disposal programs, recent DOE PAs for near-surface units (landfills, tank closures, facility closure), and international experience
- Format included groups of 2-4 presentations followed by ca. 1 hour of panel and attendee discussion; 2 full days (8 am – 6 pm).
- Ca. 75 attendees
- Organization:
  - M. Letourneau and S. Krahn (DOE)
  - D. Kosson (CRESP) and R. Seitz (SRNL)

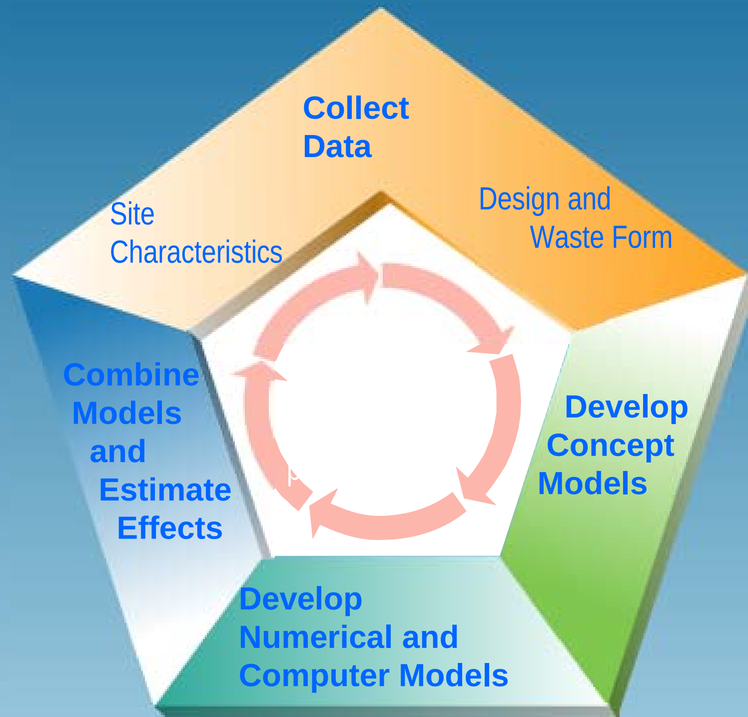
Overview of Performance Assessment

What is Performance Assessment?

- Systematic analysis of what could happen at a site

What is assessed?

- What can happen?
- How likely is it?
- What can result?



Why use it?

- Complex system
- Systematic way to evaluate data
- Internationally accepted approach

How is it conducted?

- Collect data
- Develop scientific models
- Develop computer code
- Analyze results

NRC would require a Performance Assessment to:

- Provide site and design data
- Describe barriers that isolate waste
- Evaluate features, events, and processes that affect safety
- Provide technical basis for models and inputs
- Account for variability and uncertainty
- Evaluate results from alternative models, as needed

DOE HQ Perspectives on Performance Assessments

►*Example of EM PA and PA-like Analysis Applications*


CERCLA Disposal Cell

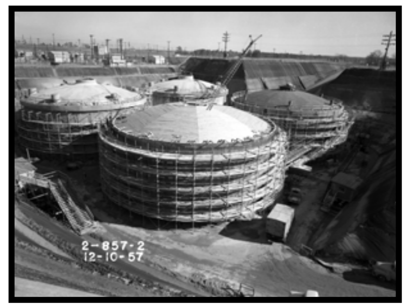

LLW Disposal Engineered Trench


LLW Disposal in Vaults

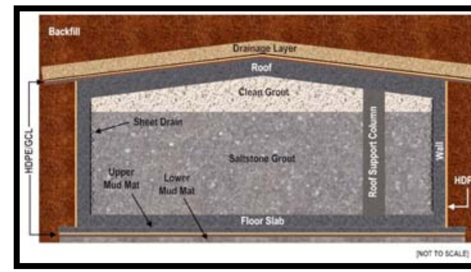

LLW Disposal Grouted in Vault


Reactor D&D


Large Facility Closure



Tank Closure



Saltstone Vault Disposal

Engineered materials assessed – grout waste form and fill, concrete containers and walls, metal tanks and containers, activated metal waste, vitrified waste, tank residual solids, contaminated soils and debris, resins,…

►*Introduction*

- DOE M 435.1 requires performance assessments (PAs) for disposal facilities and HLW closures
- High-profile closure activities (e.g., entombments) requiring more detailed PA-like analyses
- Low-Level Waste Disposal Facility Federal Review Group (LFRG) chartered to provide review function
- Community of Practice envisioned as means to foster improved consistency at individual sites and across the DOE Complex

DOE HQ Perspectives on Performance Assessments
►Perspective on PA Allowable Exposure Standards

100,000 mrem – Dose leading to ~5% chance of Fatal Cancer (UNSCEAR)

10,000 mrem/yr – IAEA mandatory intervention

5,000 mrem/yr – Worker dose standard

1,000 mrem/yr – IAEA reference level for intervention for cleanup situations

360 mrem/yr – US Average dose all sources (NCRP)

100 mrem/yr – All sources limit (IAEA practices, DOE)

25 mrem/yr – NRC and DOE LLW

15 mrem/yr – EPA Radiation (40 CFR 191)

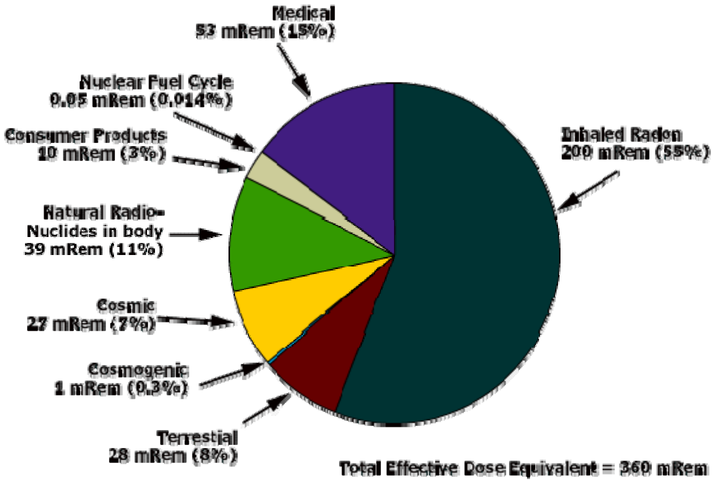
10 mrem/yr – Air (atmospheric) (40 CFR 61)

4 mrem/yr – Drinking Water (40 CFR 141)

1 mrem/yr – IAEA Exemption/Clearance

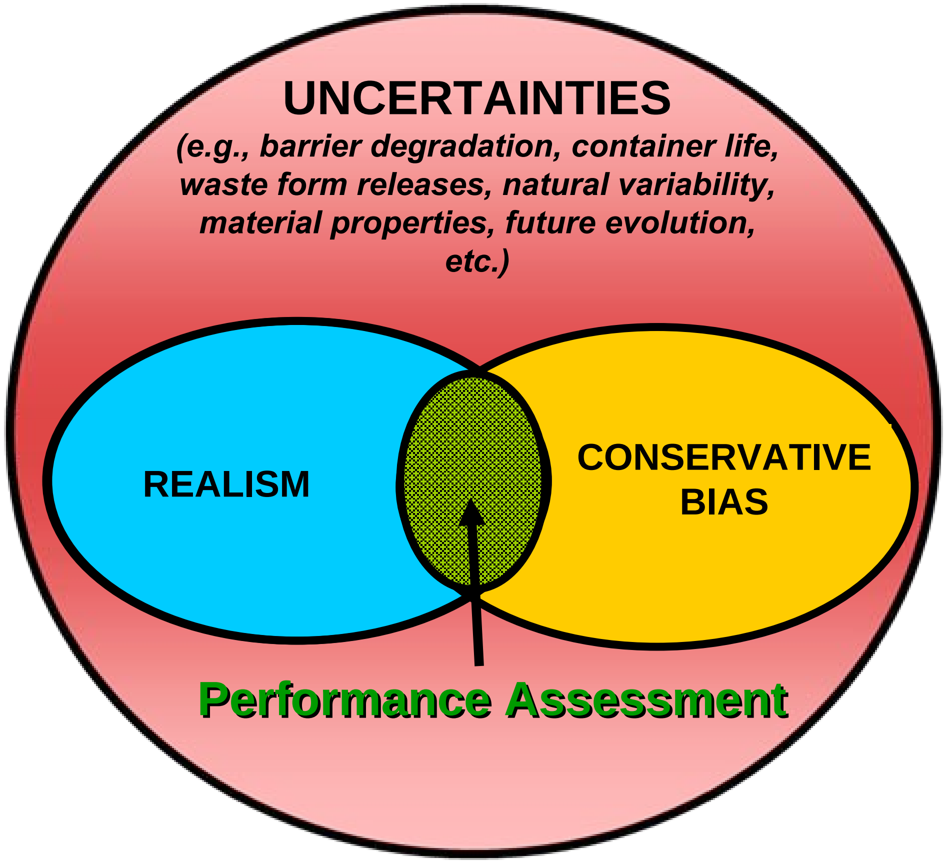
Note: Air crew average (300 mrem/yr) From UNSCEAR (2000)

Typical Annual Sources of Public Exposure



Graphics from NCRP Report No. 93

► *Realism and Conservative – Bias in PAs*



- <u>Conservative Bias</u>
  - Proven to be efficient and appropriate in many cases
  - Provides defense-in-depth and safety margin, may be overly restrictive
  - Must defend that bias is indeed conservative
- <u>Realism</u>
  - Provides more detailed understanding and credit for specific features
  - Data and models needed, can be used as support for simplified models
  - Need to focus detailed efforts where most beneficial and defensible

DOE HQ Perspectives on Performance Assessments

►Evolution of PAs

Past (Generation I)	Present (Generation II)
Deterministic	Hybrid (combination of probabilistic and deterministic methods)
Reliance on conservative-bias, less consideration of engineered features	Balance between realism and conservative-bias (probabilistic interpretation of compliance in some cases)
Conduct PA, send to regulator for review	Increased involvement with regulators and reviewers during development of PA (scoping)
Deterministic sensitivity analysis (One-Offs)	More comprehensive sensitivity and uncertainty analysis using deterministic and probabilistic methods
Minimal interaction with closure assessment modeling	Increasing coordination with closure assessment modeling efforts

Two types of approaches to PAs

- Does the *selected* engineered system approach provide adequate protection?
  - Assumes approach; is it sufficient?
- What are the *performance requirements* for system components (e.g., waste form) to assure adequate protection?
  - Seeks to identify criteria for selecting appropriate approach(es)

Reality often is iteration between questions

Major Discussion Topics and Issues
Role of PA Process in Risk Communication and Decisions

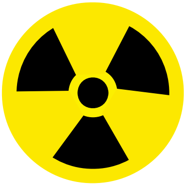
- PAs as one of several components to closure and risk-informed decisions
  - Role in regulatory review and risk communication
    - Recent success in stakeholder involvement in scoping studies and "core team" approach (F-tank farm at SRS, C-tank farm at ORP)
    - Relationships to regulatory structures and upcoming revisions to DOE 435.1 and related NRC requirements
    - Broader understanding by senior DOE management

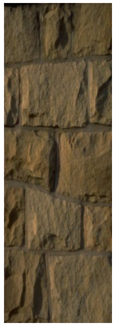
Major Discussion Topics and Issues
Modeling Improvements

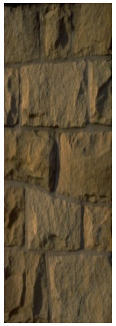
- PA models of critical system components (e.g., waste forms, barriers) should be based on fundamental understanding of release and degradation mechanisms
  - Graded approach based on system component significance and sensitivity analysis, often with conservatism to ensure safety.
  - Engineered materials related to role of system component in overall “safety case” (e.g., physical, hydraulic and/or chemical barrier).
  - Models need to be supported by data (experiments, measurements) at multiple scales.
  - Challenges in modeling coupled physical, chemical and hydraulic phenomena
  - Challenges in scale-up while assuring fidelity to actual behavior
    - Spatial scales, dimensionality (3-D, 2-D, 1-D), spatial averaging
    - Temporal scales and temporal averaging – importance of “event driven” processes (e.g., infiltration, seismic)
  - Phenomenological models, once validated, can be abstracted effectively to facilitate model integration.

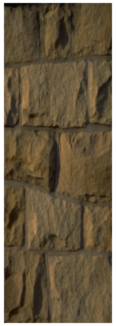
Overview of Data and Modeling Considerations for Engineered Features

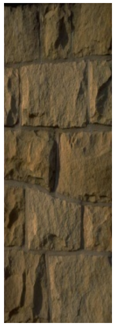
►*Role of Engineered Materials in Iterative Approach*

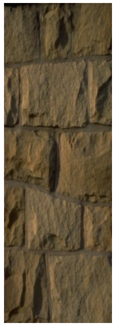








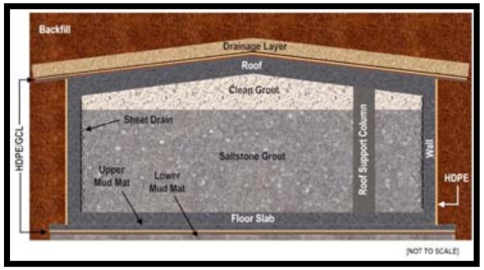




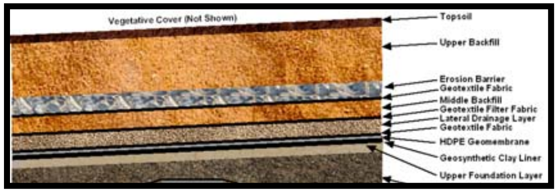
Waste Form | Container | Vault, Liner | Cover | Site

Geochemistry, Permeability

Physical Isolation



Physical Isolation and Chemical Control



EM Environmental Management

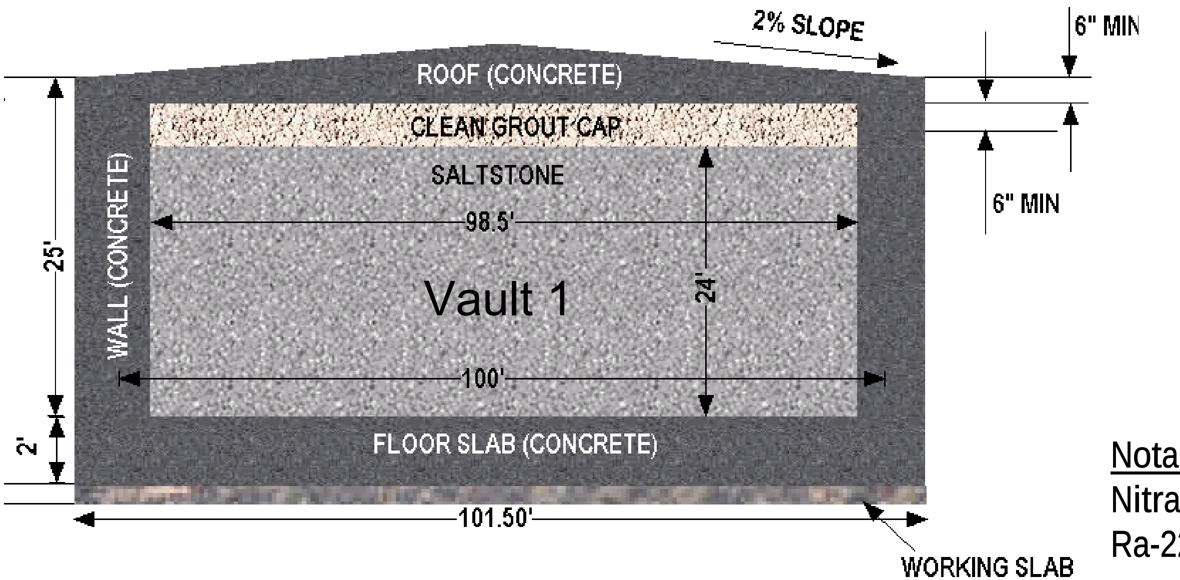
safety ❖ performance ❖ cleanup ❖ closure

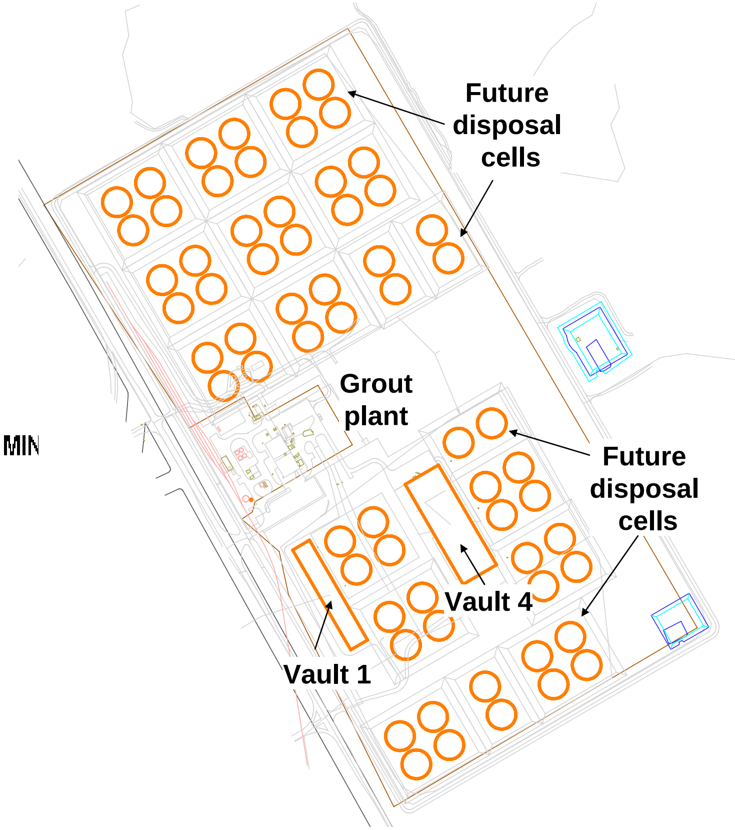
Presented by Roger R. Seitz, SRNL
Performance Assessment Community of Practice

Contaminant Release from Cementitious Materials: Savannah River Practice

► Saltstone Disposal Facility

- Salt liquid waste mixed with dry grout to form "Saltstone"
- Blast furnace slag in Saltstone grout and vault concrete to create reducing conditions





Notable species

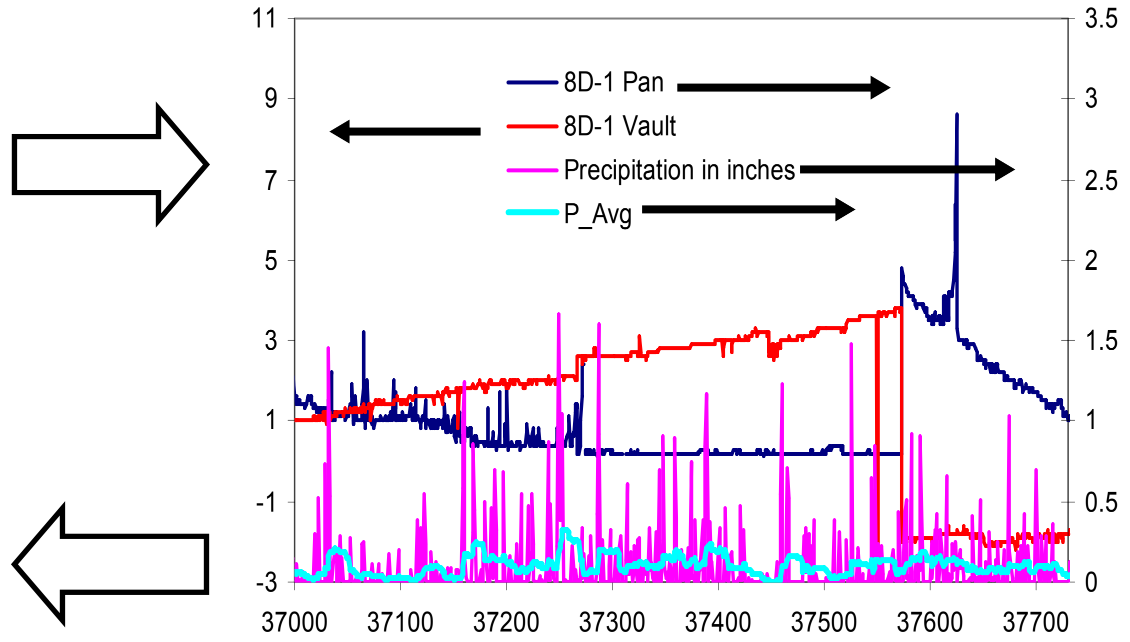
Nitrate, Tc-99, I-129 and Ra-226 ingrowth from Th-230

►*Critical Importance of Model Assumptions and Results Validation*

Original Conceptual Model:

-Buried concrete vaults would limit water entering the system

-Thick unsaturated zone would limit transport (Idaho)



Observations:

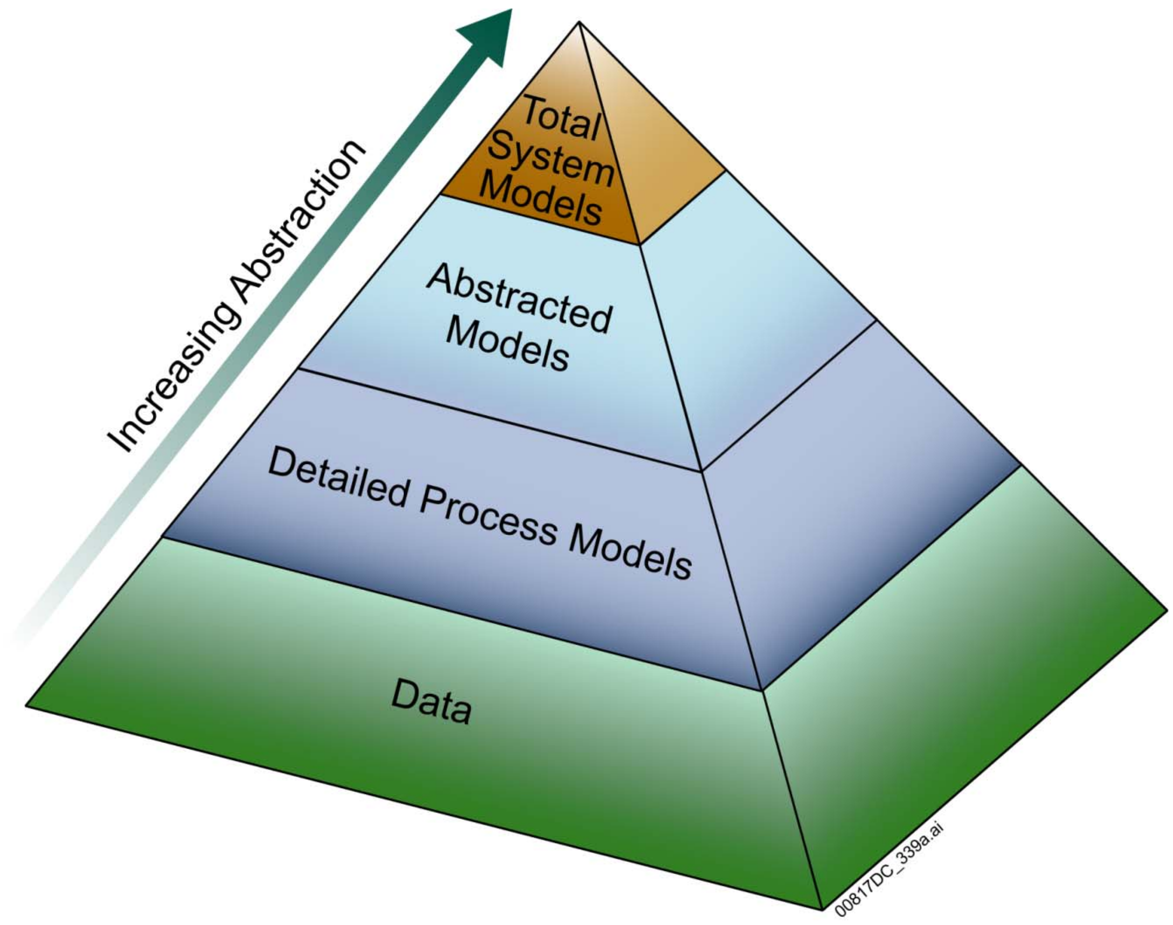
-Dynamic snowmelt and precipitation events results in infiltration through cracks and joints in the vaults

-Transport to saturated zone through discrete features much more rapid than anticipated (observed from spills)

- Sufficient detail in temporal and spatial data needs to be included.

Model Integration:
An Example from the Yucca Mountain License Application

►Construct Integrated System Model



Major Discussion Topics and Issues
PA Assumption Validation

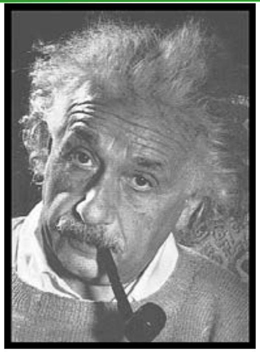
Relationships between PA assumptions, system design, and performance confirmation

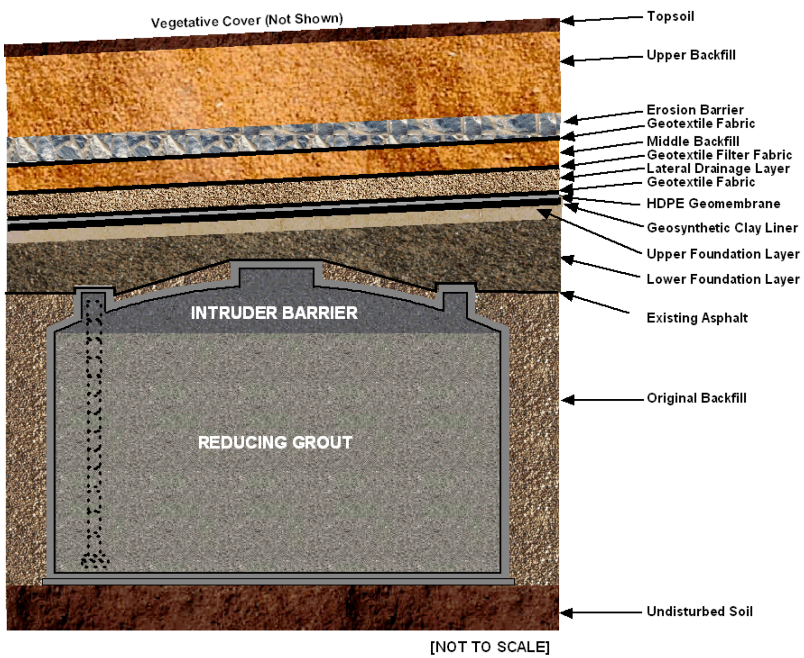
- Testing of actual waste, waste form samples, barrier components
- Multiple scales of performance evaluation
  - Focused on system components and intended functions
  - Field testing of performance of initial and anticipated degraded states (e.g., lysimeter testing)
  - Engineering-scale demonstrations and evaluations
- Performance monitoring vs. compliance monitoring
  - Performance monitoring to assess/verify performance of system components
  - Focused on "leading indicators" and actual performance
  - Potentially part of future requirements
- Potential need for improved collaboration between PA developers, system designers and system constructors/operators
  - Include independent review/evaluation of key performance predictions in contract requirements?
- Relationship to EM Technology Development and Demonstration (TDD) Program?
  - Better integration between Site contractor efforts and TDD program schedules needed?

Overview of Data and Modeling Considerations for Engineered Features

►Complexity and Data Needs

- Desire to represent more detail and take credit for more features (Operational and Scientific)
- Requires more complex models, which require more data with more complexity to defend
- Choices between defending realism and conservative-bias





What is Conservative?

Complexity

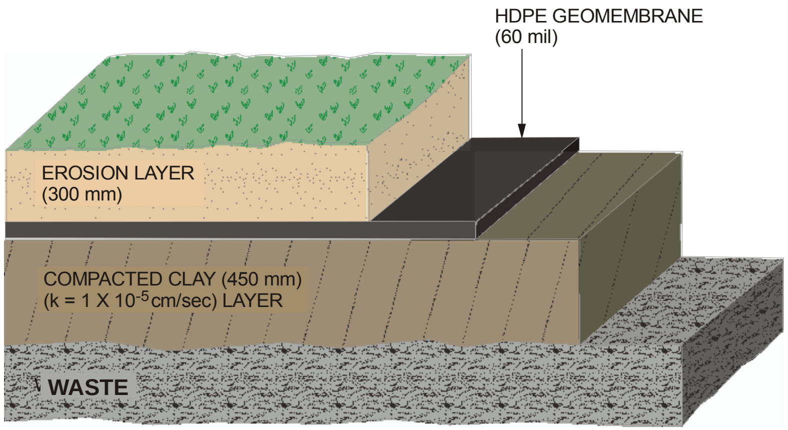
- Size and distribution of fractures?
- Interactions between carbonation, sulfate attack, oxidation, etc. and effects on fracture formation/healing?
- Link of cover failure with degradation of cementitious materials?
- Fracture effects on oxidation rate of bulk waste?

Conservative Assumptions ??

- Early cover failure
- Early failure of the grout and vault

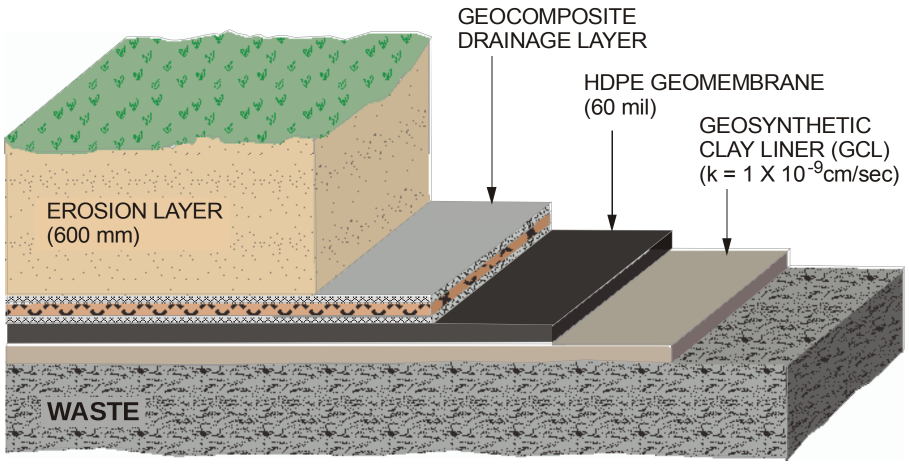
Modeling Performance and Degradation of Covers and Liners

►Conventional Final Covers



Conventional Cover System

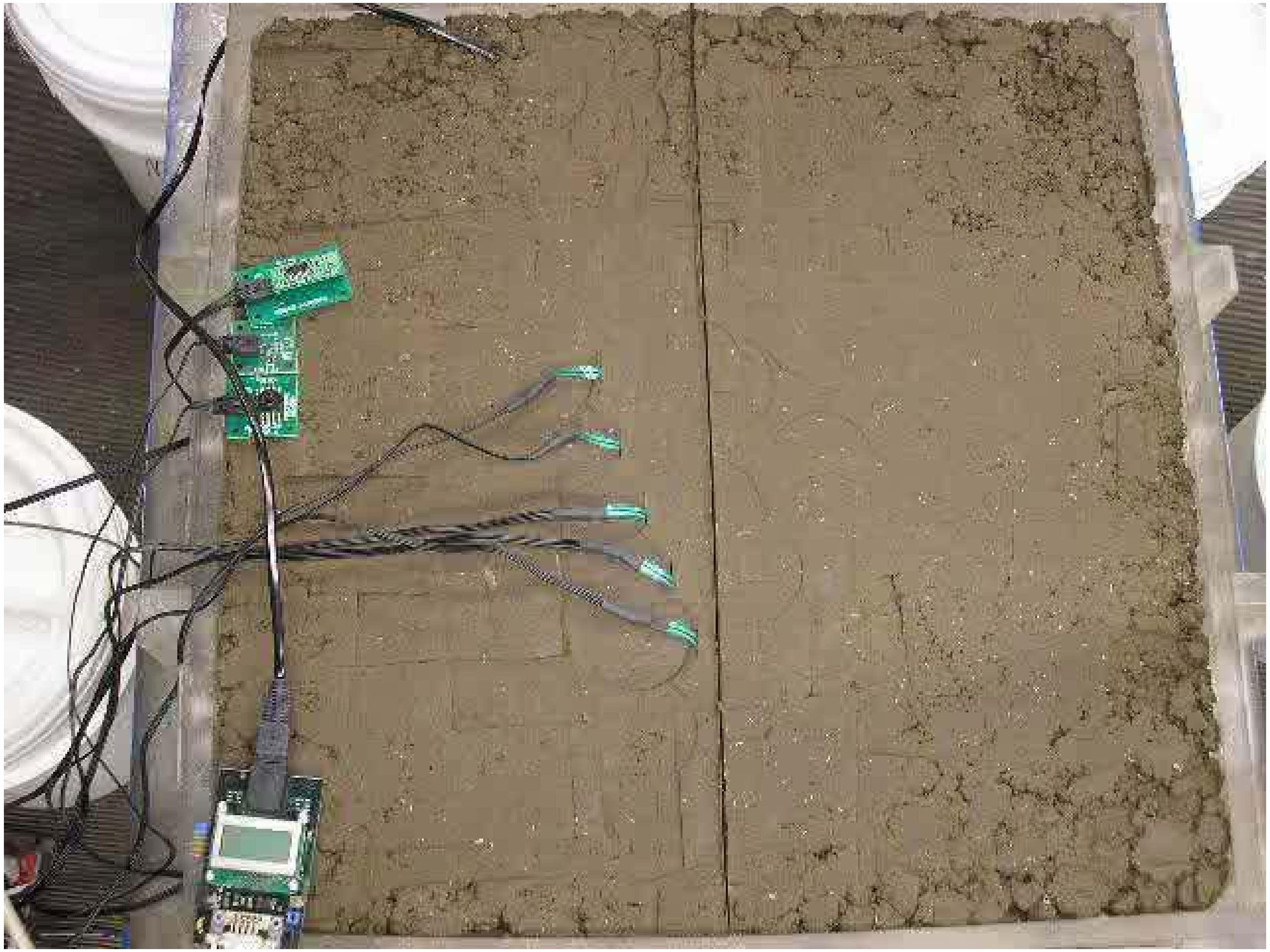
Conventional Cover with Geosynthetics



Figures courtesy M. Othman,
Geosyntec Consultants

Field Scale Lysimeters / Lab Experiments on Clay Cracking

►Example



Field Scale Lysimeters / Lab Experiments on Clay Cracking

►*Example*

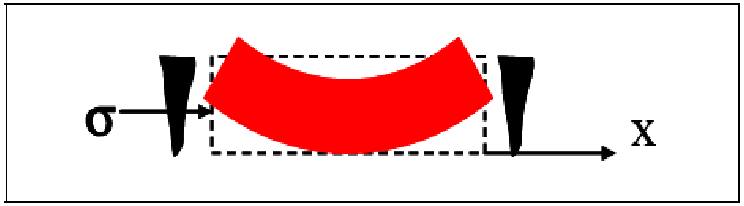
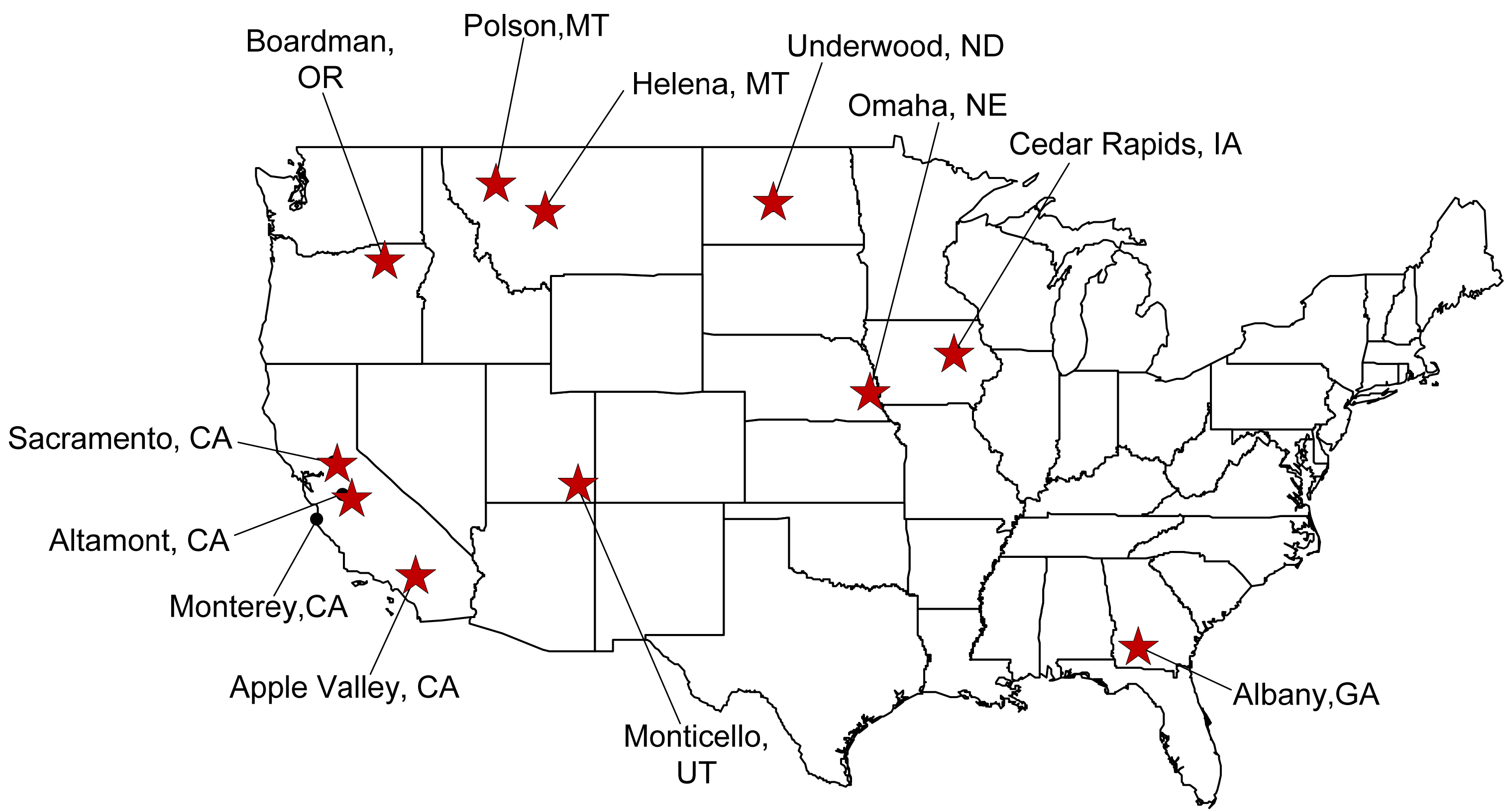


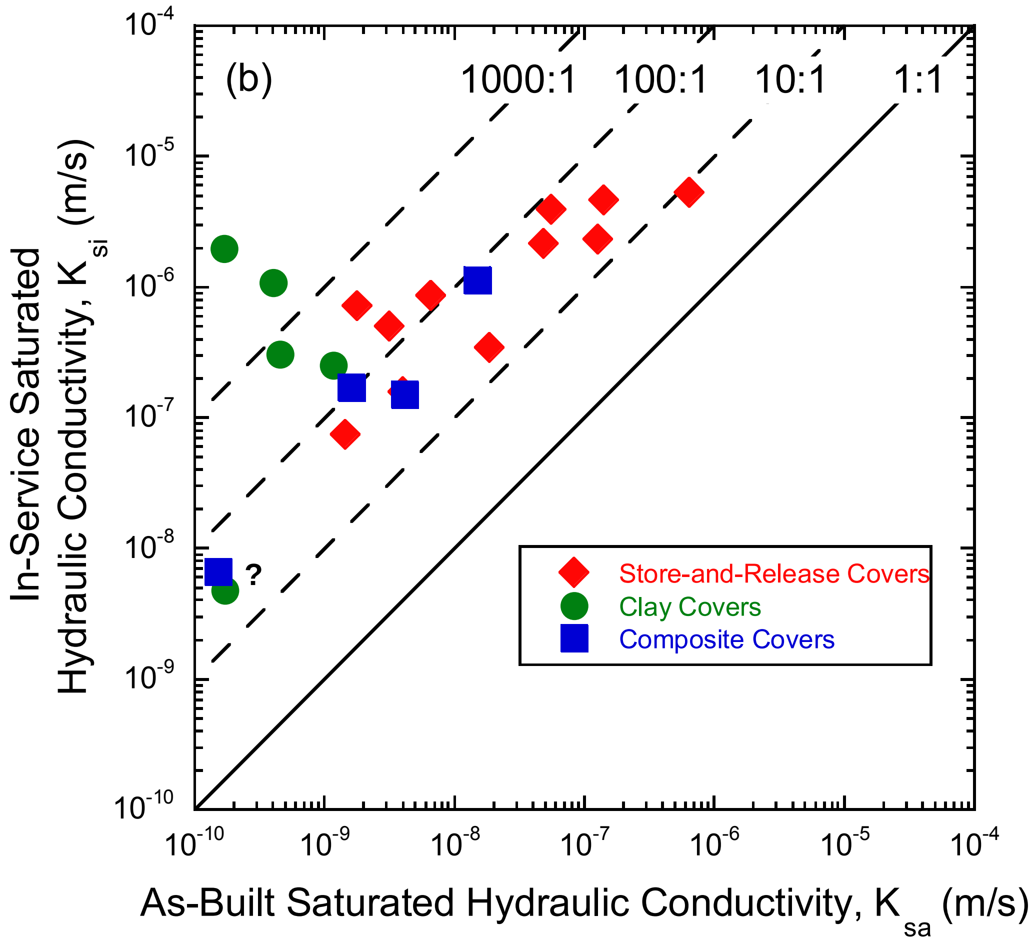
Figure 45. Curling response of soil undergoing changes in lateral tension.

Figure 46. Surface curling in clay mass after 2 days.

ACAP Exhumation Study



▶ Earthen Barriers – Saturated Hydraulic Conductivity



Saturated hydraulic conductivity of ALL barriers increased at least 10x.

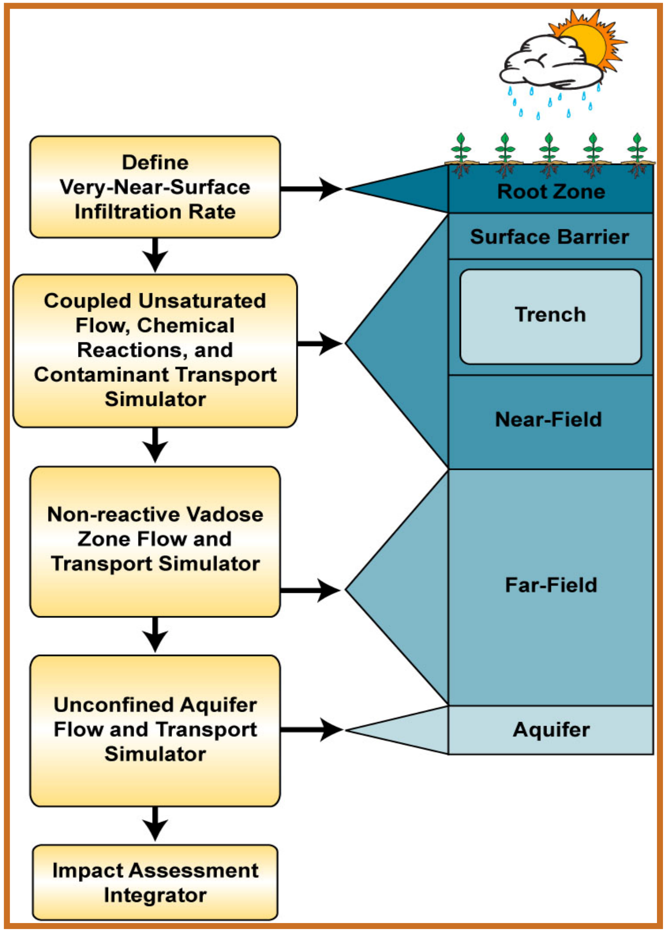
None of the conventional covers had hydraulic conductivity < 10^{-9} m/s, common regulatory standard.

No relationship with as-built hydraulic conductivity.

Strategy to Predict Radionuclide Release from Glass Waste Forms

►*Overview of Integrated Strategy*

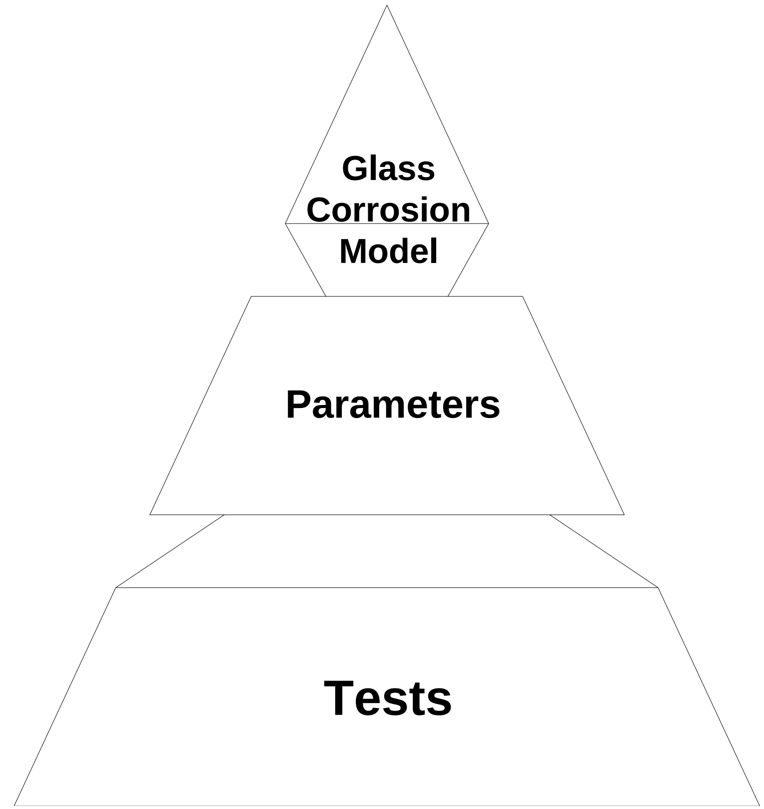
- Subsurface water and gas flow
- Waste glass dissolution
- Transport of aqueous and gaseous chemical species
- Kinetic and equilibrium chemical reactions
- Secondary mineral dissolution and precipitation
- Coupling between hydraulic properties and mineral precipitation and dissolution



Strategy to Predict Radionuclide Release from Glass Waste Forms

►Integrated Strategy, cont.

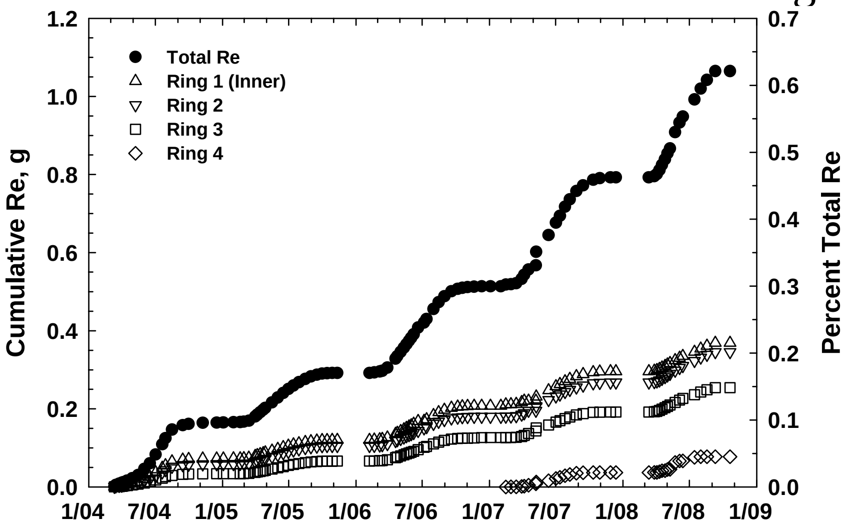
- Glasses tested span the expected WTP processing
- Laboratory Tests Methods:
  - VHT, PCT, MCC-1, SPFT, & PUF
- Quantify parameters from test data
- Parameterize Glass Corrosion Model (rate law)
- Validate Rate Law through lab and field-scale experiments
  - PUF experiments (column test)
  - Lysimeter experiments

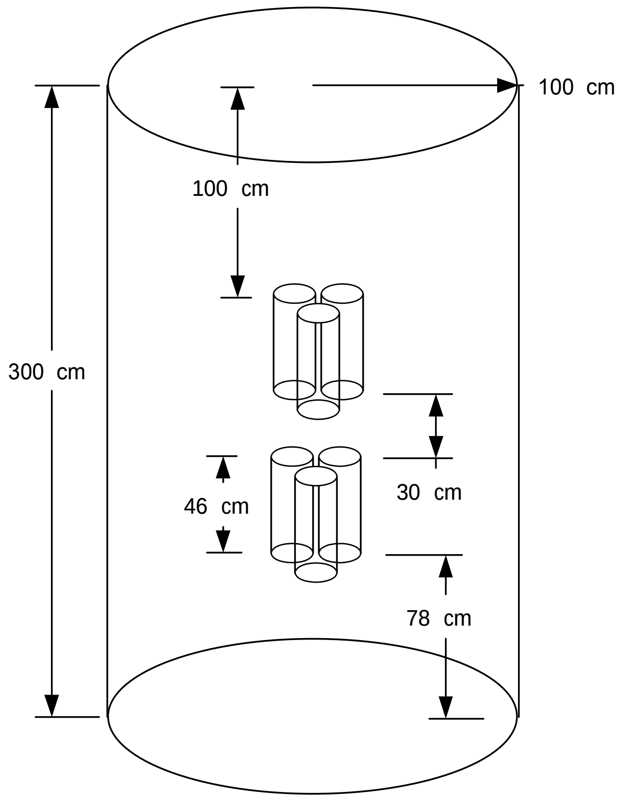


Strategy to Predict Radionuclide Release from Glass Waste Forms

►Integrated Strategy – Model Validation

- 3 glass containing lysimeters were buried on site
  - 2 durable glasses (actual WTP glass)
  - 1 less durable glass (HAN28F)
- Six 40-kg glass cylinders buried in 2002 per lysimeter
- 3-times the natural infiltration rate via irrigation





Re (chemical analogue for Tc-99) release from HAN28F glass (poorly durable glass).

Strategy to Predict Radionuclide Release from Glass Waste Forms
► *Next Step*

- Son of GLAMOR
  - DOE-NE funded
  - Participants: US Nat. Lab/University and International research
- Develop consensus rate law for glass corrosion in range of disposal environments
- Focus on improving the understanding of residual rate, r_∞
- Facilitate model development
  - Near-field model → modeling and simulation activity
  - Capture process level detail across-scales

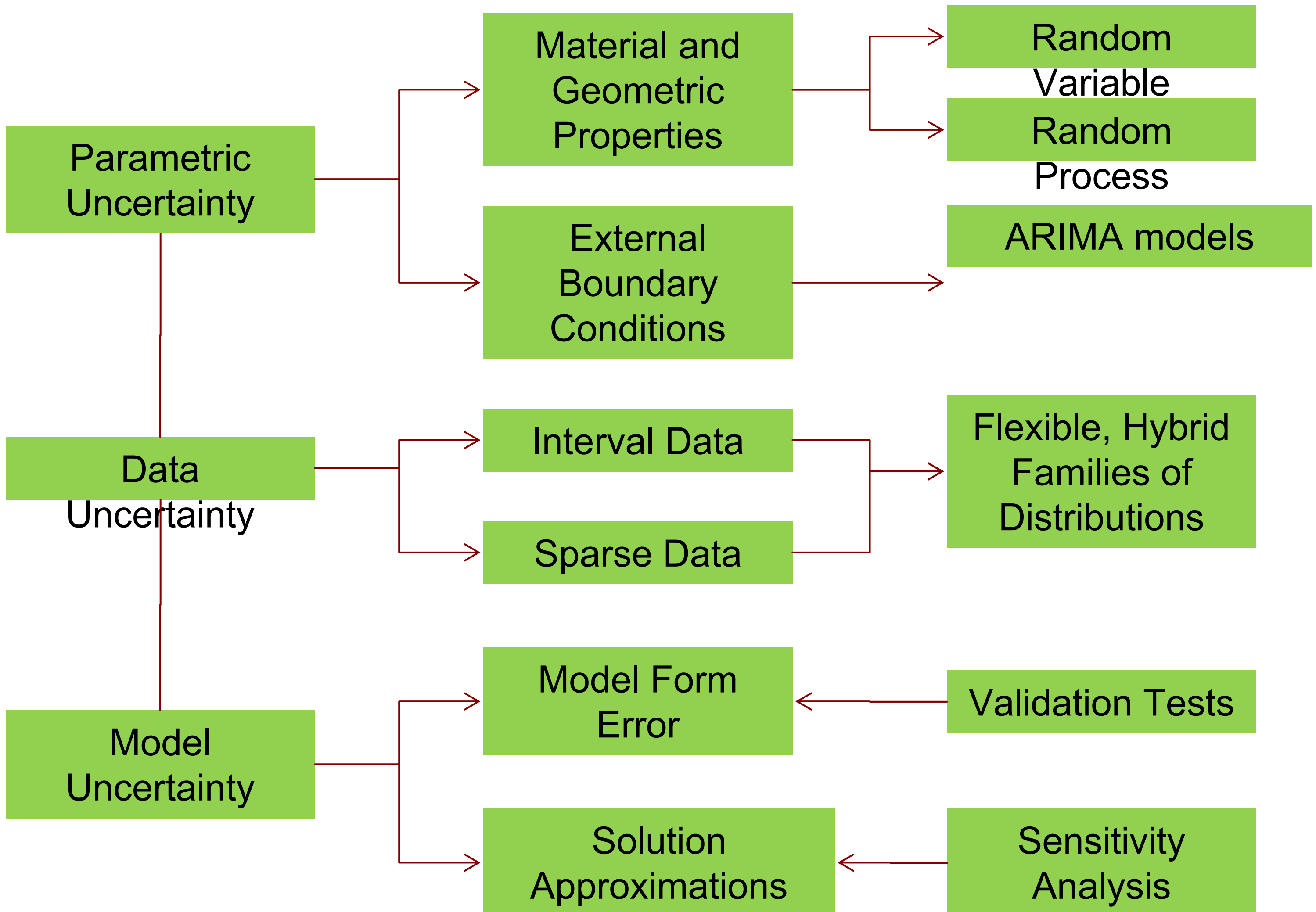
P. van Iseghem, S. Gin, B. Grambow, B. P. McGrail, D.M. Strachan, and G. Wick (2003). *A critical evaluation of the dissolution mechanism of HLW glasses in conditions of relevance for geologic disposal*. R-3702, European Commission.

Major Discussion Topics and Issues Uncertainty Evaluation

Uncertainty Evaluation

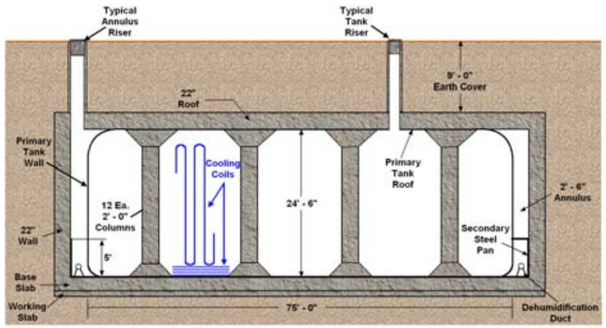
- Current State-of-the-art is hybrid approach
  - “Best estimate” deterministic case with sensitivity analysis
  - Probabilistic evaluation with parameter distributions for most sensitive variables
- Multiple forms and sources of uncertainty
- Need for structure approach for developing parameter distributions
  - Yucca Mountain experience provides example structured approach
  - Focused on system components and intended functions
  - Need for data and appropriate data selection to support case/scenario-specific distributions
- Need for improved evaluation and decision basis that incorporates results of probabilistic evaluations
  - “Peak of the means” may not be most appropriate approach
  - Technical and regulatory foundation needed

Sources of Uncertainty

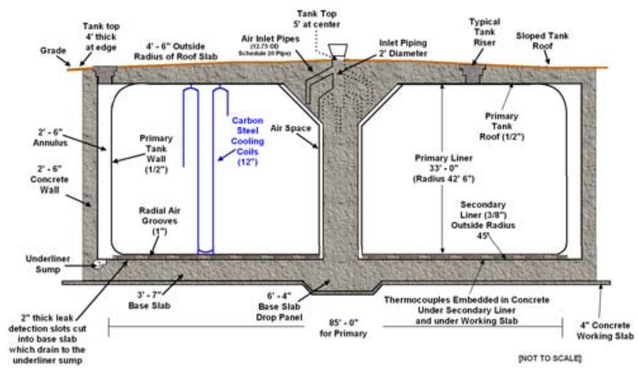


Life Estimation of High Level Waste Tank Steel for F-Tank Farm Closure Performance Assessment

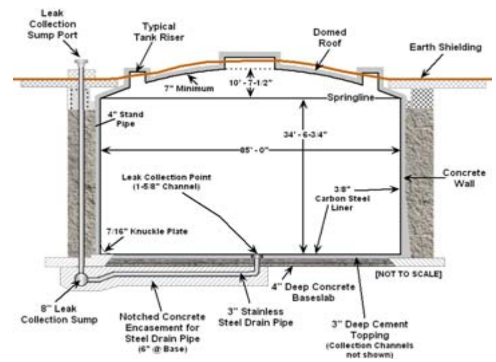
►*F-Tank Farm Liquid Waste Tanks*



- Type I Tanks
- Vintage 1950s
- Built of ASTM A285, Grade B
- Non-stress relieved
- Partial secondary containment
- 0.5-in plate construction



- Type III/IIIA Tanks
- Vintage 1970s-1980s
- Built of ASTM A537-Cl.1, A516-70
- Stress relieved
- Full secondary containment
- Tapered design from 0.5-in to 0.875-in thickness



- Type IV Tanks
- Steel-lined prestressed concrete tank
- ASTM A285 Grade B Steel
- 0.375-in thick walls
- 0.4375-in thick bottom
- Vintage 1950s

►*Corrosion in Concrete/Grout*

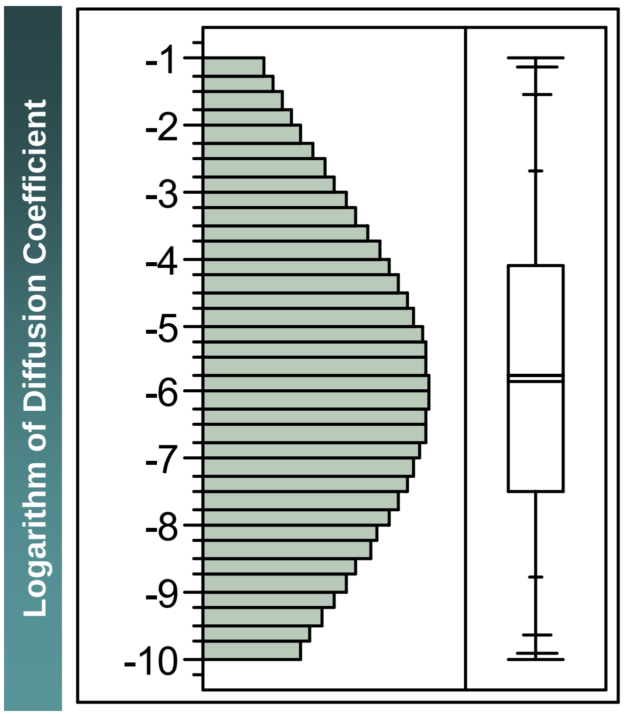
- Corrosion of steel exposed to concrete/grout occurs by a complex mechanism that occurs through metal dissolution at the concrete/metal interface.
- Concrete generally prevents corrosion of the steel
  - Forms passive oxide on the steel surface
  - Maintains a high pH environment
  - Provides a matrix resistant to diffusion of aggressive species
- Passivity can be lost through carbonation or through chloride induced film breakdown
  - Pore water characteristics change with the introduction of chlorides or carbon dioxide, the passive film on the steel may break down

►*Stochastic Technical Approach*

- Proposed to account for potential uncertainty in the time-frames proposed for regulatory compliance
- Initially Considered
  - First order reliability methods (FORM)
    - Statistical information is sparse
    - Marginal probability distributions
  - Direct uncertainty analysis
    - Separation of the probability calculations from the evaluation of the performance measure
    - Discretization of the probability intervals
- Ultimately, USED Monte Carlo Simulation
  - Inherently represent the uncertainties in the deterministic approach
  - Large number of simulations
  - Exploits the in-depth knowledge of SRS subsurface environments and HLW tanks as input distributions for the simulations

Life Estimation of High Level Waste Tank Steel for F-Tank Farm Closure Performance Assessment

►*Diffusion Coefficient Input*

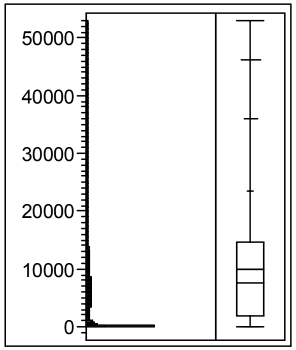


quantiles		
100.0%	max	0.10000
99.5%		0.07509
97.5%		0.02822
90.0%		0.00215
75.0%	quartile	0.00008
50.0%	median	1.47e-6
25.0%	quartile	3.06e-8
10.0%		1.68e-9
2.5%		2.3e-10
0.5%		1.2e-10
0.0%	min	1e-10

Life Estimation of High Level Waste Tank Steel for F-Tank Farm Closure Performance Assessment

►*Type I Monte Carlo Simulation*

Time to Failure



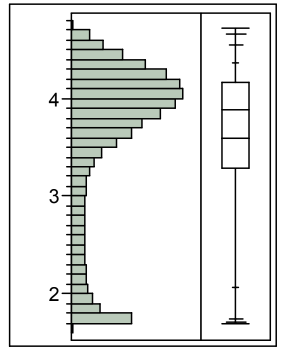
Quantiles

100.0%	maximum	52887
99.5%		46227
97.5%		36154
90.0%		23481
75.0%	quartile	14679
50.0%	median	7630
25.0%	quartile	1925
10.0%		115
2.5%		55
0.5%		51
0.0%	minimum	49

Moments

Mean	9982.4153
Std Dev	9791.9605
Std Err Mean	8.8182837
upper 95% Mean	9999.6988
lower 95% Mean	9965.1317
N	1233023

Log Time to Failure:



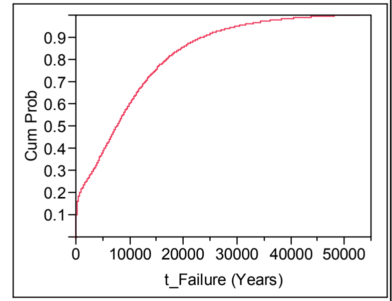
Quantiles

100.0%	maximum	4.7234
99.5%		4.6649
97.5%		4.5582
90.0%		4.3707
75.0%	quartile	4.1667
50.0%	median	3.8825
25.0%	quartile	3.2844
10.0%		2.0619
2.5%		1.7402
0.5%		1.7115
0.0%	minimum	1.6918

Moments

Mean	3.5948208
Std Dev	0.8144007
Std Err Mean	0.0007334
upper 95% Mean	3.5962583
lower 95% Mean	3.5933834
N	1233023

CDF Plot

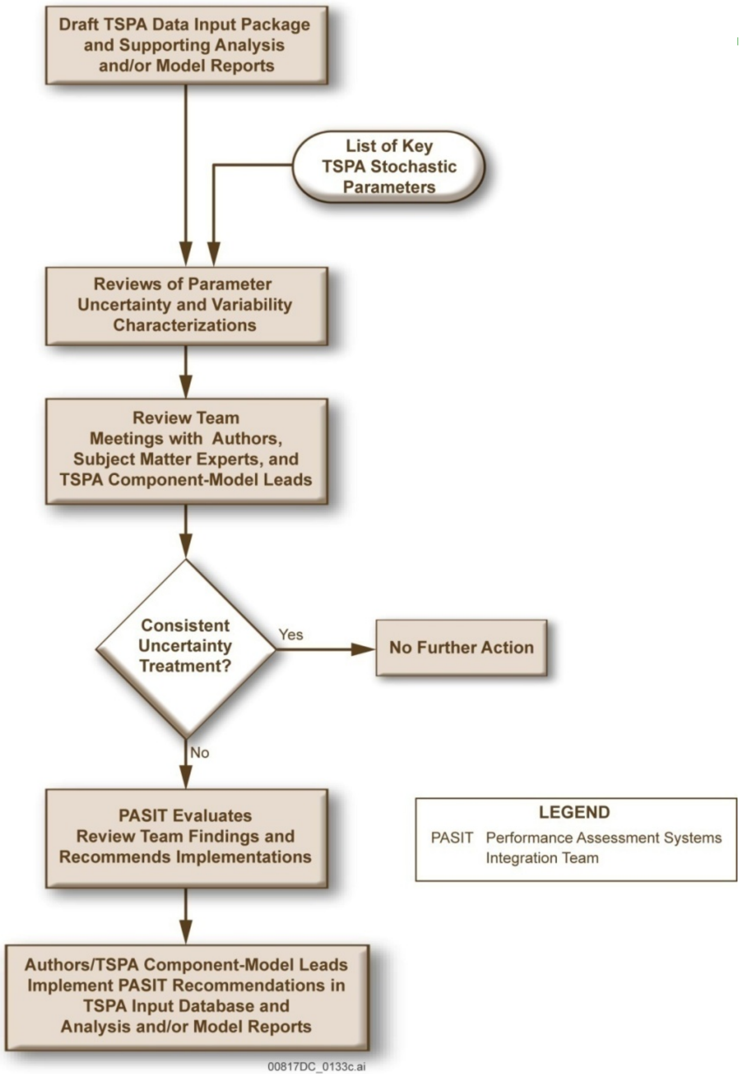


Failure Mode Frequency

Level	Count	Prob
0	440223	0.35703
1	792800	0.64297
Total	1233023	1.00000

►*PUT Parameter Review Process*

- Review relevant source documents
- Meetings with authors, data collectors, SMEs, and analysts
- Develop recommendations and/or independent probabilistic representations
- Present findings and recommendations to SMEs and appropriate technical management
- If necessary, a senior technical management team decides on the appropriate uncertainty implementation, based on a risk-informed perspective



Major Discussion Topics and Issues
Evolving US EPA Developments

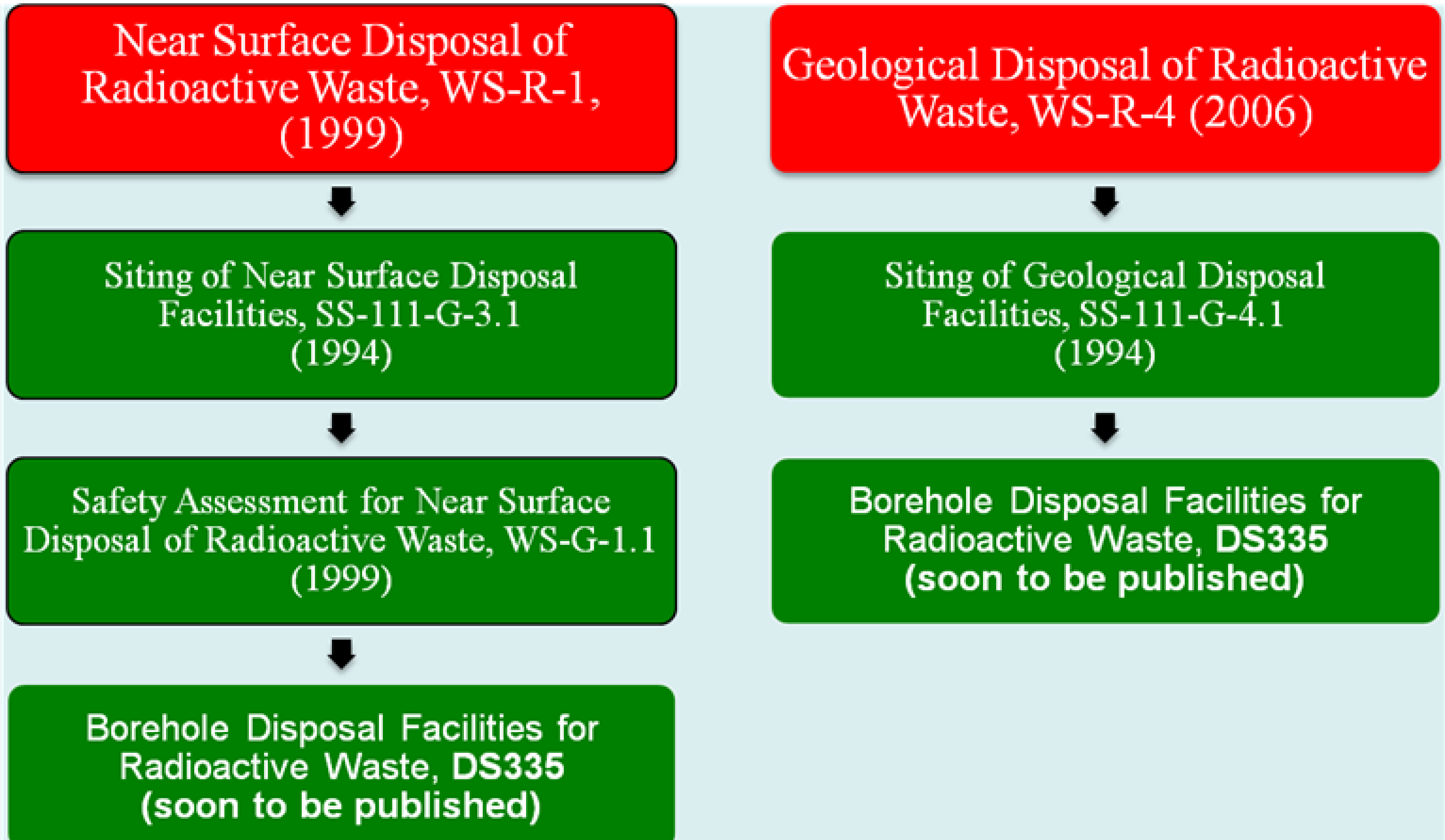
- New leaching test methods (currently SW-846 Draft Methods)
  - Suite of several tests estimate pH-dependent release and mass transfer rates
  - Provide for more mechanistic assessment of waste form and materials performance
  - Applicable to many current uses of leaching tests (e.g., delisting, determinations of equivalent treatment, RCRA consolidate waste management units) but not Sub-title C determinations
  - Collaboration between DOE and EPA under discussion, including inter-laboratory (round robin) testing for validation

- Anticipated new proposed regulations for coal fly ash
  - Triggered by fly ash release at TVA facility in Kingston, TN (Dec. 2008)
  - Planned for end of calendar year proposal
  - Has the potential for far-reaching implications for DOE
    - Use in concrete construction
    - Use in waste forms (disposal application)
    - Management of coal combustion residues at major sites (legacy materials)

Related IAEA Activities

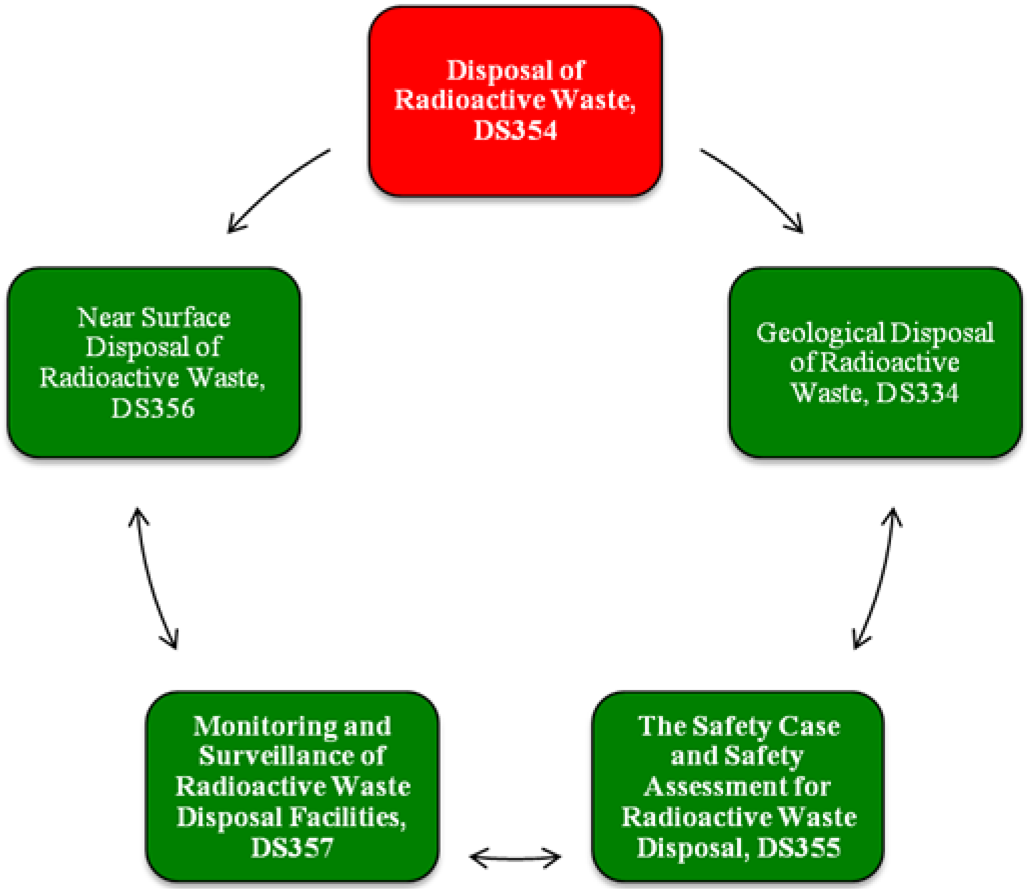
IAEA Activities on Safety Assessment and Radioactive Waste Management

►IAEA Safety Standards for Disposal of Radioactive Waste, Before Comprehensive Plan:



IAEA Activities on Safety Assessment and Radioactive Waste Management

► ***Going Forward – an integrated package of standards for disposal of radioactive waste:***



1. Introduction
2. Overview of Near Surface Disposal and its Implementation
3. Legal and Organizational Infrastructure
4. Safety Approach and Design Principles
5. Safety Case and Safety Assessment
6. Implementation of the Disposal Project
7. Existing Disposal Facilities

Appendix I: Siting of Near Surface Disposal Facilities
Appendix II: Post-Closure Safety Assessment

►*Upcoming Events*

- International workshop on *Post-closure monitoring and surveillance of repositories* to mark the 10th anniversary of the closure of Centre de la Manche, Cherbourg, France, 2009 September 22-25.
- *International Conference Effective Nuclear Regulatory Systems: Further Enhancing the Global Nuclear Safety and Security Regime*, 2009 December 14-18, Cape Town, South Africa.
- A one-day side event of the international conference in Cape Town is the *International Workshop on Demonstrating the Safety and Licensing of Radioactive Waste Disposal*. 2009 December 14.
- *International Conference on the management of spent nuclear fuel from nuclear power reactors.* 2010 May 31-June 3, Vienna.

PA CoP – Looking Forward

DOE HQ Perspectives on Performance Assessments

- Provide means to address consistency early and throughout PA process
- Foster early and sustained communication among LLW, Tank Closure, NEPA, CERCLA, and D&D assessors
- Provide forum to share information regarding state of the art and specific models, data and approaches
- Serve as an enduring data and modeling resource to minimize duplication of effort across DOE and train future generation of PA professionals
- Allow LFRG to focus on its original mission

► Still more HQ Perspective

- Future potential PA CoP activities include:
  - Participation in 435.1 update activities
  - More workshops, lessons learned, technology transfer
- Consistency does not mean uniformity
  - Continued ability to defend our analysis is paramount
- A true Community of Practice should benefit all

PA CoP – Looking Forward

Additional suggestions

- PA CoP benefits
  - Information repository with PA related information
  - Being able to send one or more experts to assist with a specific issue (PA assistance team concept)
  - Better formalization of processes associated with preparing a PA
- Important Technical Exchange meeting topics
  - Discussion of quantification of reasonable assurance (deterministic and probabilistic approaches)
  - Approaches to consider alternative conceptual models and scenarios in PAs
  - Risk communication as part of the PA process

Perspectives Change Based on Data