Cementitious Barriers Partnership

Project Number 08.1.3.1.7, DOE-EM 21

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14 July 2009

Partnership Members

- **Department of Energy – Office of Environmental Management**
  - ➢ Principal supporting agency
  - ➢ Primary end-user
- **Nuclear Regulatory Commission**
  - ➢ Oversight & Research Divisions
  - ➢ Primary end-user
- **National Institute of Standards and Technology**
- **Savannah River National Laboratory**
- **Vanderbilt University/ Consortium for Risk Evaluation with Stakeholder Participation (CRESP)**
- **Energy Research Centre of the Netherlands**
- **SIMCO**

Expert Advisory Panel organized through CRESP Independent Peer Review Board

Project Goal

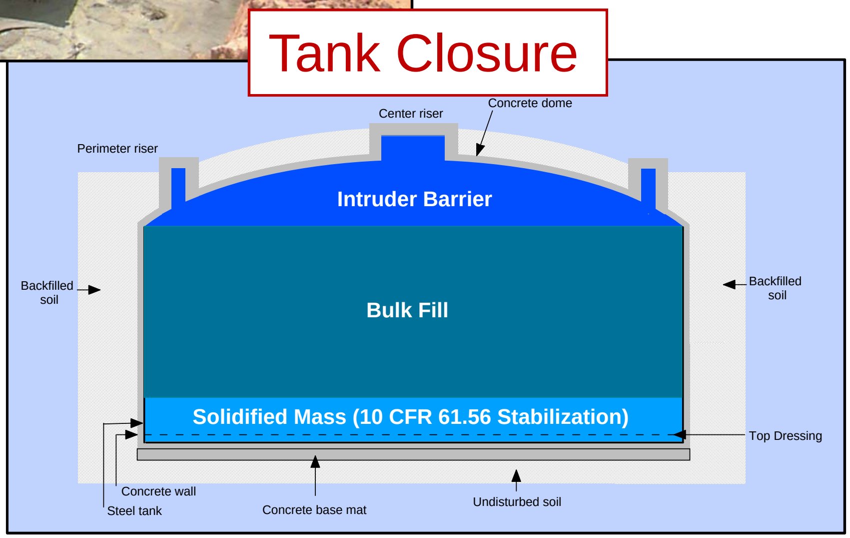
➢ Develop a reasonable and credible set of tools to predict the structural, hydraulic and chemical performance of cement barriers used in nuclear applications over extended time frames (e.g., >100 years for operating facilities and > 1000 years for waste management).

- Mechanistic / Phenomenological Basis
- Parameter Estimation and Measurement
- Boundary Conditions (physical, chemical interfaces)
- Uncertainty Characterization

Safety and Risk Issues

- Current PA approach may not adequately represent risk and uncertainty of disposal and containment systems and practices
  - Waste form selection, contaminant loading, optimization
  - Disposal decisions
  - Remediation and D&D options evaluations
- Need improved basis for understanding materials performance beyond initial design life
  - Service life extension for existing facilities
- Design improvements of future facilities may not be realized due to lack of mechanistic understanding of cementitious barrier performance

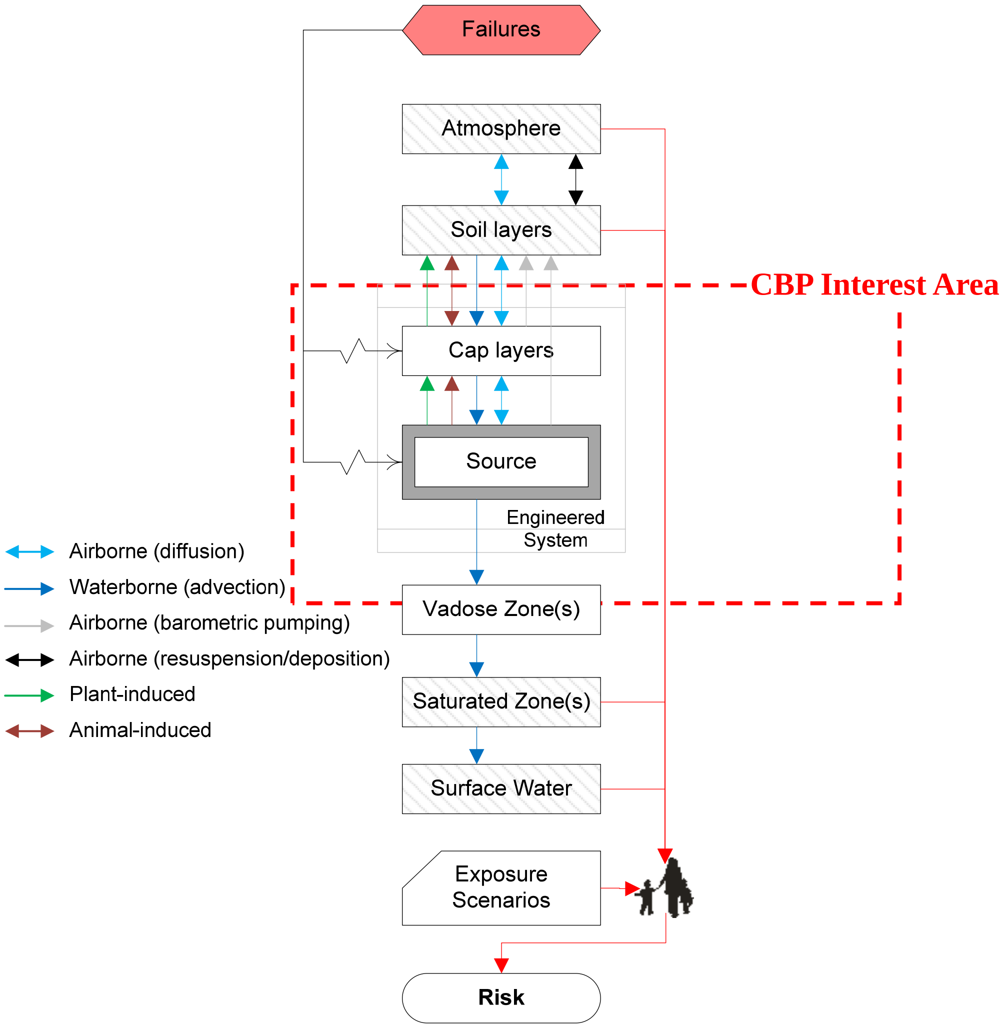
DOE Applications



Technical Strategy / Approach

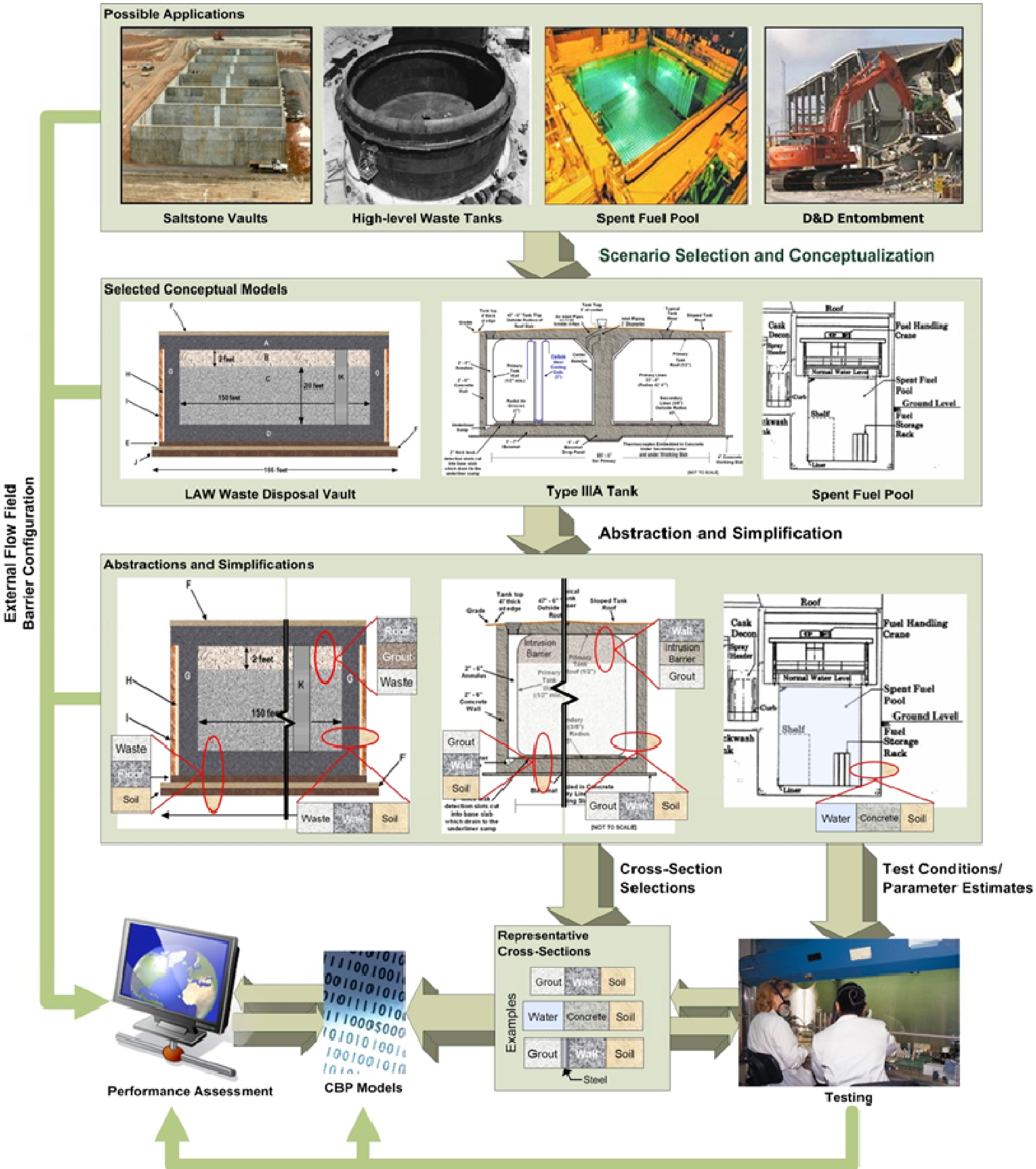
- **Reference Cases – provide basis for comparison and demonstration of tools under development**
  - Cementitious waste form in concrete disposal vault with cap
  - Grouted high level waste tank
  - Spent fuel pool
  - Materials – surrogate LAW cementitious waste form, reducing grout, reinforced concrete (historical), reinforced concrete (future)
- **Extension/enhancement of existing tools –** CEMHYD3D/Thames, Stadium, LeachXS/Orchestra, GoldSim PA framework
- **Coordinated experimental and computational program**
  - Conceptual model improvement
  - Define test methods and Parameter measurements
  - Model validation

Integration of CBP Tools with PAs



CBP focus:

- Cementitious materials performance as part of engineered system and their interfaces with natural system
- To provide near field source term
- Uncertainty approach being developed to be broadly applicable to PA and design process.



Linking Prototype Cases to Performance Models through System Abstraction

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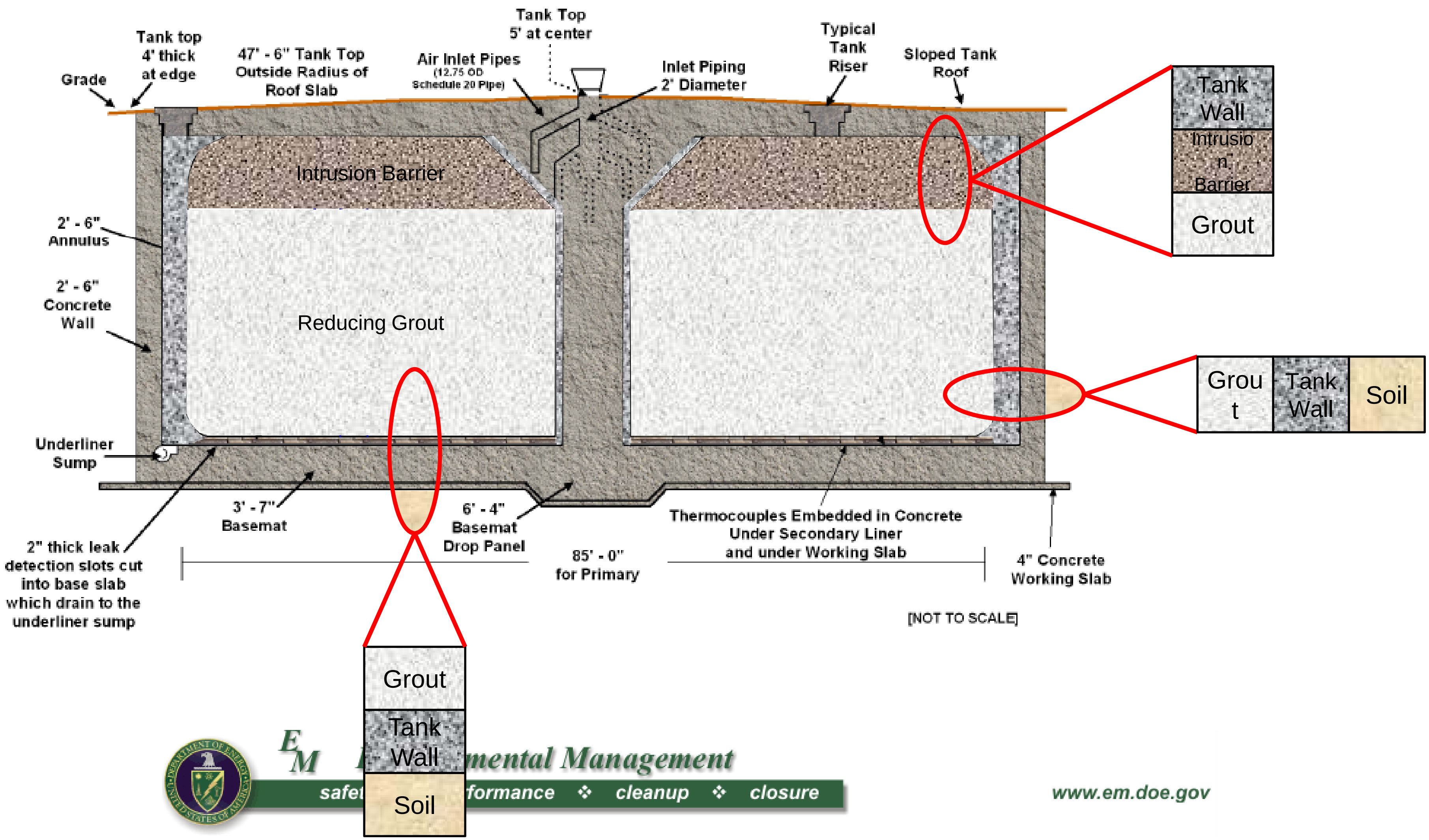
Type IIIA Tank – Conceptual Closure Model



Integrated Long-Term Degradation

Chemical degradation and physical structure evolution are coupled.

<u>Physical stress</u>

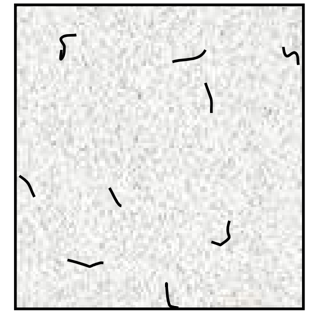
- External loading
- Drying shrinkage
- Seismic events
- Settlement

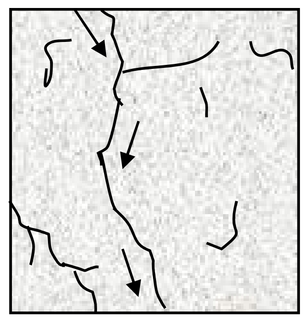
<u>Chemical Alteration</u>

- Oxidation, Leaching
- Pore & crack evolution
  - Dissolution and cracking
  - Precipitation & sealing
- Expansive reactions & corrosion
  - Carbonation
  - Sulfate attack
  - Rebar corrosion

Microcracks

- Increase porosity
- Increase interaction pore water/surface



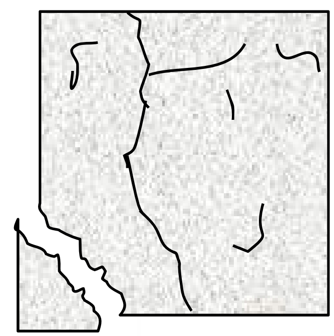


Through-cracks

- Preferential flow path
- Diffusive and convective release
- Loss of strength

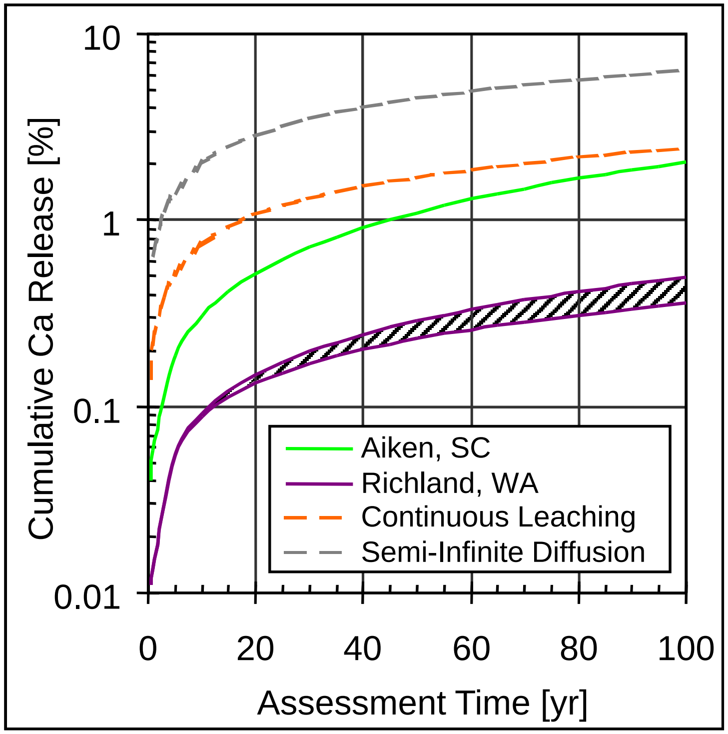
Spalling

- Loss of cohesiveness
  - Two body problem
- Eventual release from “granular” material

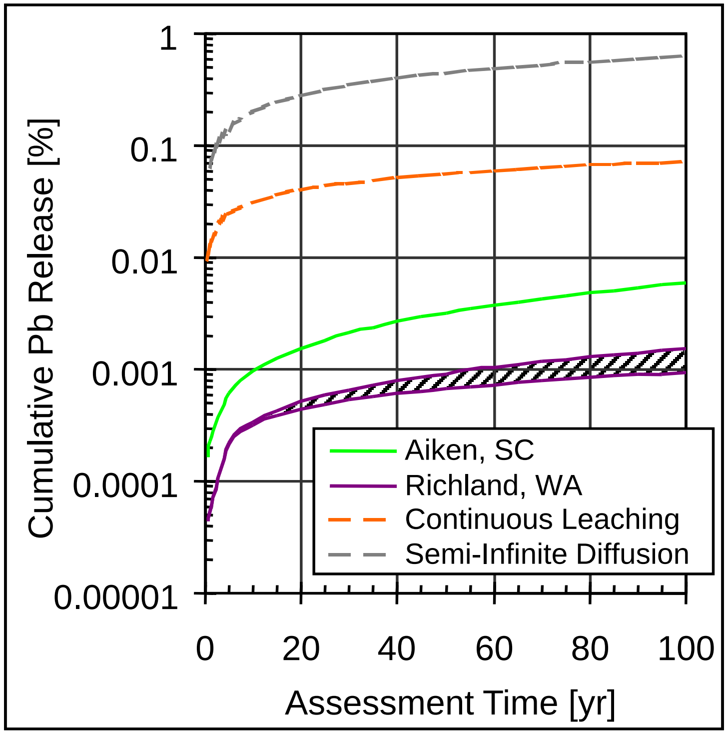


Impact of Model Assumptions - Examples

- **Leaching over Time** : Comparison of release estimates using the (i) simple diffusion, (ii) chemistry & saturated conditions and (iii) chemistry & intermittent infiltration.

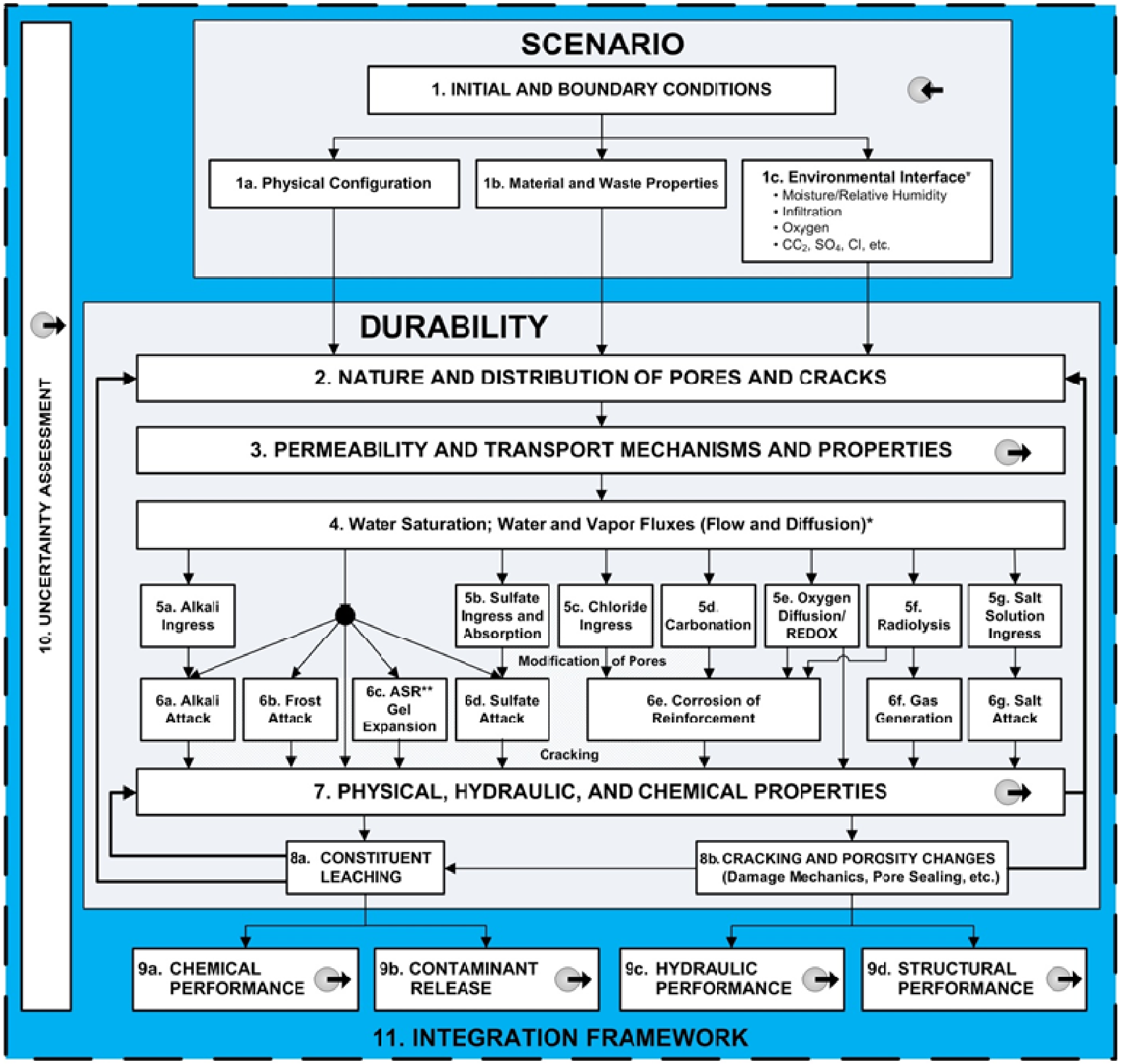


Calcium



Lead

Specifications, Properties, and Phenomena for the Evaluation of Performance of Cementitious Barriers

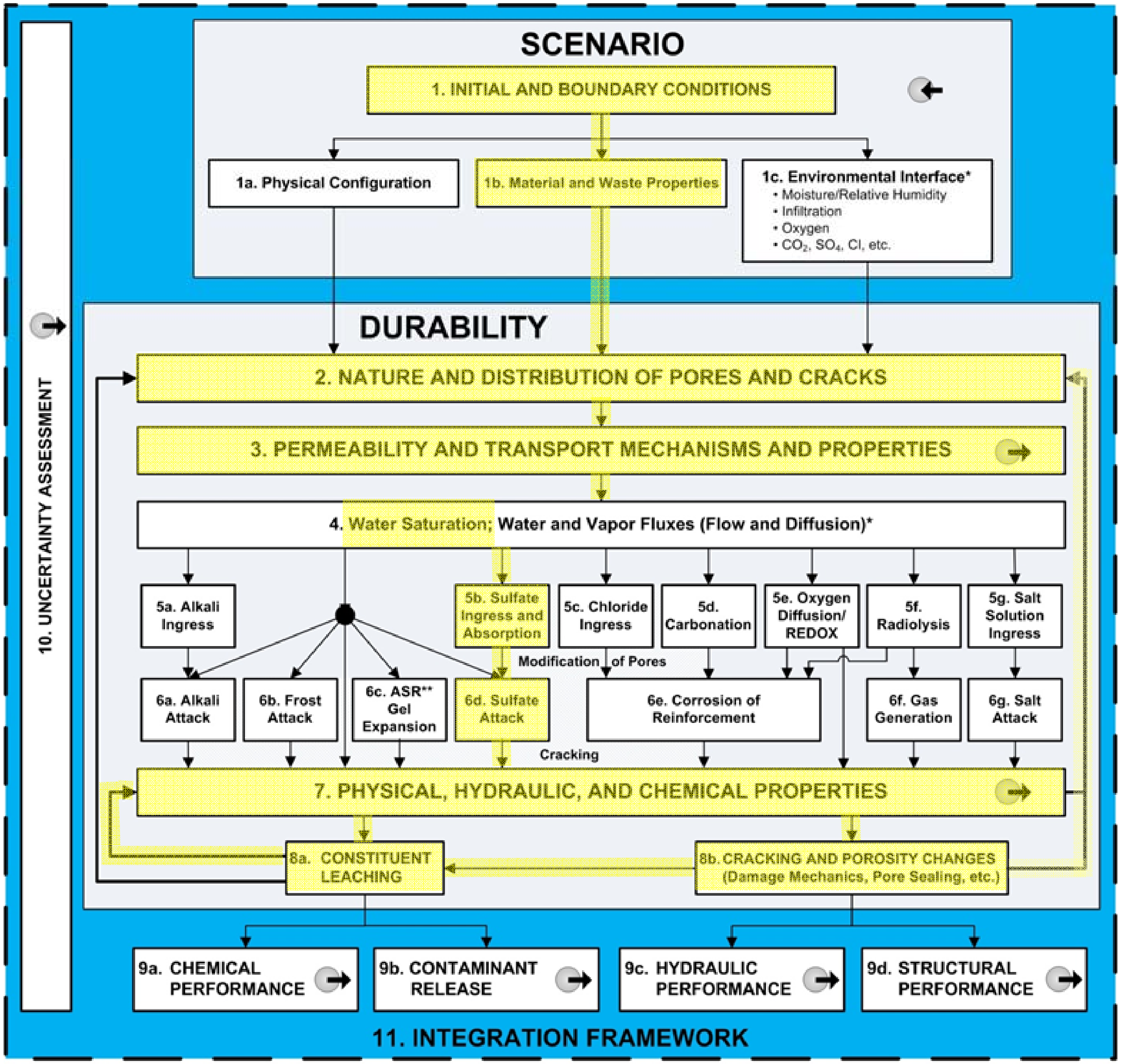


* Includes external flow field from PA fate and transport modeling (e.g., PORFLOW for SRNL, STOMP for PNNL, etc.)
** ASR = alkali-silica reaction

FROM PA systems modeling

TO PA systems modeling

Sulfate Attack as a "proof of principle" for coupling of phenomena



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FROM PA systems modeling

TO PA systems modeling

Summary of USDOE and USNRC Performance Assessment Approaches: Modeling and Uncertainty

Kevin G. Brown, VU/CRESP, Roger R. Seitz, SRNL,
Glenn A. Taylor, SRNL, David W. Esh, USNRC

- Modeling Approaches
  - Performance Assessments
  - Other Risk Assessment Approaches
- Uncertainty Approaches
  - Performance Assessments
  - Other Risk Assessment Approaches
- Key Assumptions
- Major Findings

Performance Assessment Examples

- Tank Farm Facility Performance Assessment (INL)
- Radioactive Waste Management Complex (INL)
- Hanford Integrated Disposal Facility (Hanford Site)
- Solid Waste Storage Area 6 (ORNL)
- F-Tank Farm Performance Assessment (SRS)
- E-Area Low-level Waste Facility (SRS)
- US Nuclear Regulatory Commission (USNRC) Applications

Examples for Other Assessments

- Disposition of Radioactive Waste Management Complex under CERCLA (Idaho)
- Landfill Closure of the Waste Calcining Facility under RCRA and NEPA Environmental Assessment (Idaho)
- Tanks 17-F and 20-F Closure Actions under SCDHEC Industrial Wastewater Permits and NEPA Environmental Impact Statement (SRS)
- P Reactor In-Situ Decommissioning under CERCLA (SRS)
- 221-U Facility Remedial Actions under CERCLA and NEPA (Hanford)
- Final EIS for the Tank Waste Remediation System under NEPA (Hanford)
- Decommissioning under the USNRC License Termination Rule and Environmental Assessment (Big Rock Point)

Summary and Key Assumptions

- Examples provided for LLW disposal facilities, D&D, and remediation of DOE and other contaminated sites.
  - Assessments vary in source/release assumptions, transport pathways, exposure scenarios, and whether dose/risk limits are mandated.
  - Credit taken in source term, release and near field transport.
  - Cementitious materials serve as physical and chemical barriers.
- Key assumptions related to release
  - Credit taken ranged from no credit to large credit for physical and chemical properties, including timing of degradation.
  - Gross simplifying assumptions for cementitious materials performance.
  - Assumptions adopted because of lack of specific information or defense for assumptions associated with detailed consideration.

Cementitious Materials as a Physical Barrier

- Physical failure often represented as a change in bulk hydraulic conductivity resulting from cracking.
  - Prior to cracking, often assumed that releases controlled by diffusion.
- Cracking is critical as it alters flows of water/vapor through waste form and diffusion properties.
  - Simplifying assumptions made because of difficulties in quantifying the extent and impact of cracking.
  - Different approaches were used to identify the onset of cracking.
  - Lack of ability to take credit for more gradual changes as cracking progresses.

Cementitious Materials as a Chemical Barrier

- The most common consideration is use of linear partition coefficients to account for chemical retention.
- Presence of reducing conditions in a grouted waste is an important consideration for the assessments.
- Solubilities are recently being developed for specific radionuclides in a cementitious matrix.

KEY PA KNOWLEDGE GAPS AND CBP APPROACHES TO REDUCE THESE GAPS

What are the initial conditions (after a few months to years) of cementitious materials and waste forms with respect to physical integrity (e.g., potential cracking, gaps at interfaces) and chemical conditions (e.g., oxidation, carbonation)?

- Approach: Field test beds and characterization of core samples from existing structures and facilities will provide improved knowledge of initial conditions as a function of material and system design and environmental exposure scenario.
- Approach: THAMES and planned enhancements addresses the prediction of solid phase mineralogy and transport properties (e.g., permeability, diffusion tortuosity) as a function of material composition and curing conditions.
- Approach: Testing of materials (beginning with reference case materials) in conjunction with assembling existing and new materials characteristics into a database will reduce uncertainty in properties of materials, such as primary mix compositions of grouts, reinforced concretes and waste forms in nuclear applications.

KEY PA KNOWLEDGE GAPS AND CBP APPROACHES TO REDUCE THESE GAPS

What are the effects of primary aging processes (e.g., primary constituent leaching, carbonation, oxidation, sulfate ingress, chloride ingress) on transport (e.g., permeability) and chemical properties of barrier materials that impact constituent release, structural durability and hydraulic containment or isolation?

What is the impact of coupling of multiple physical (e.g., cracking) and chemical (e.g., oxidation) processes?

- Approach: STADIUM and planned enhancements addresses the effects of aging processes on structural and hydraulic durability.
- Approach: LeachXS/Orchestra and planned enhancements address the effects of aging processes on chemical properties and constituent release (leaching).
- Approach: THAMES and planned enhancements addresses the effects of changing material composition in response to aging processes on solid phase mineralogy and transport properties (e.g., permeability, diffusion tortuosity).
- Approach: Model integration with coupling to PA models (e.g. Poreflow) will facilitate of evaluation of specific phenomena and uncertainties that relate to specific PA scenarios.

KEY PA KNOWLEDGE GAPS AND CBP APPROACHES TO REDUCE THESE GAPS

What are the effects of event driven processes that have highly non-linear responses (e.g., infiltration events coupled with wetting and drying phenomena) in contrast to temporal averaging (e.g., average annual infiltration)?

- Approach: Planned enhancements to STADIUM and LeachXS/Orchestra will permit the evaluation of the impact of event driven processes versus temporal averaging on estimates of structural durability and constituent release. Sensitivity analysis with respect to temporal averaging on CBP Reference Cases will assess the importance of these phenomena.

KEY PA KNOWLEDGE GAPS AND CBP APPROACHES TO REDUCE THESE GAPS

What is the impact of simplifying assumptions (e.g., saturated or constant unsaturated conditions, constant composition boundary conditions) on constituent release?

- Approach: STADIUM and LeachXS/Orchestra will be used to evaluate the relative importance of various simplifying assumptions on overall system performance.

CBP - Expected Impact

- Computational tools for performance assessment and design
- Reduce data gaps for relevant systems
- Reduced uncertainty and improved consistency for PAs
- Updated guidance documents (assessment tools, test methods, data)
- Improved system designs (waste management and new facilities)
- Monitoring and maintenance approaches for extended (100s, 1000s yr) service life
- Industry-wide technical basis for evaluation amongst stakeholders (DOE, NRC, state regulators, others)
- Assessment transparency