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Studies

Treatment of Engineered Barriers in TSPA-SR

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Presented by:
S. David Sevougian, TSPA Core Team
DE&S/CRWMS M&O
Performance Assessment Operations

U.S. Department of Energy
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Overview

- This presentation focuses on changes from TSPA-VA to TSPA-SR in the engineered-barrier-system models:
  - Waste package and drip shield (WP PMR)
  - Waste form (WF PMR)
  - In-drift geochemical environment (EBS PMR)
  - EBS transport (EBS PMR)

Drivers for Model Changes

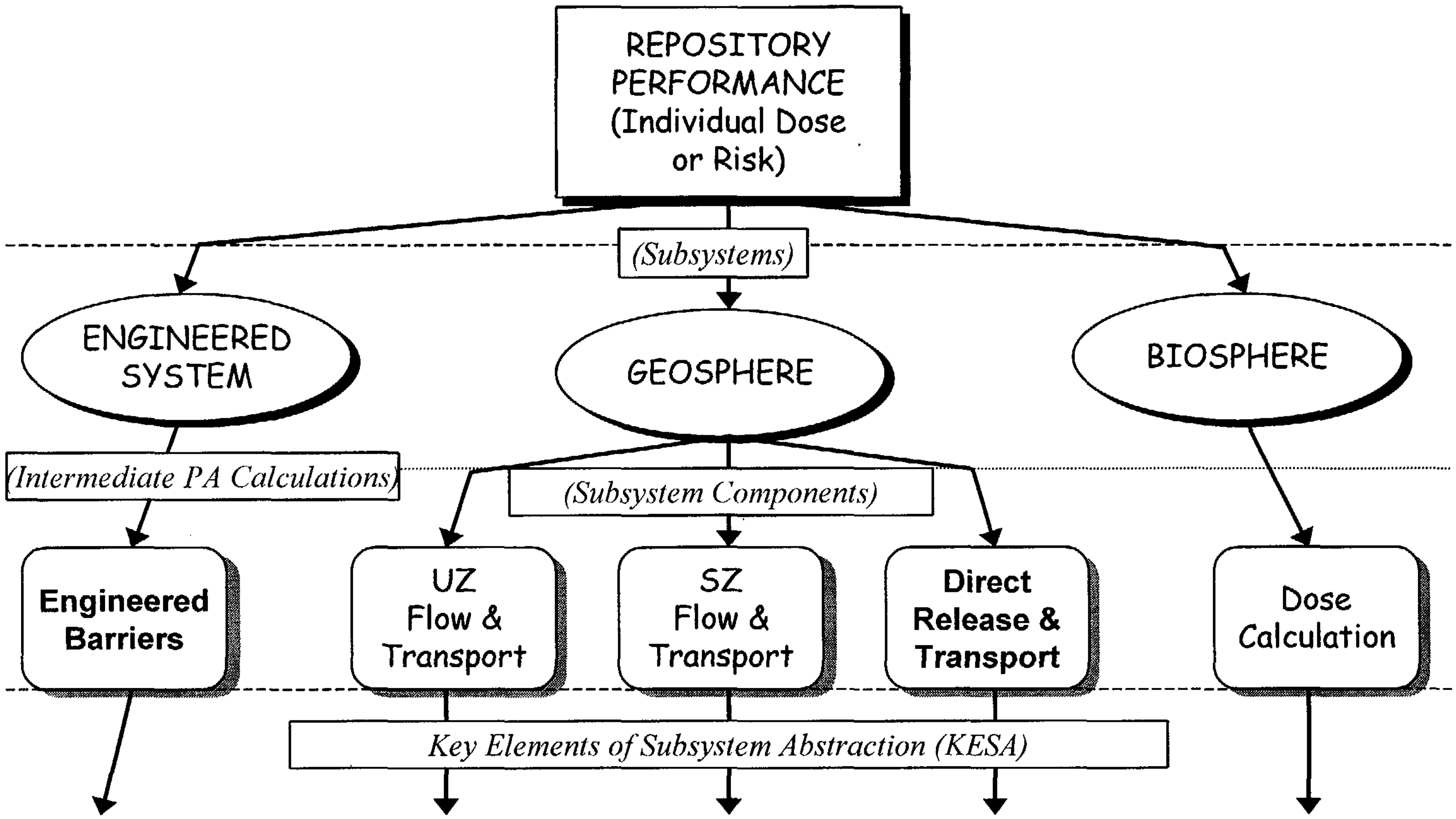
- Regulatory requirements
  - NRC IRSRs and associated acceptance criteria
  - New regulations (proposed NRC 10 CFR Part 63; EPA 40 CFR Part 197)
- Design requirements
  - New repository design
  - New waste package design (including drip shield)

Drivers for Model Changes
(Continued)

- Technical requirements
  - NRC, NWTRB, and PAPR comments on adequacy of models and data used in TSPA-VA
  - New data for several models
- Quality assurance requirements—control and traceability of
  - Data
  - Models & analyses
  - Software

NRC Key Technical Issues and IRSRs Relevant to the Engineered Barriers

- Container life and source term
- Evolution of the near-field environment
- Igneous activity
- Repository design and thermal-mechanical effects
- Structural deformation and seismicity
- Thermal effects on flow
- Total system performance assessment and integration

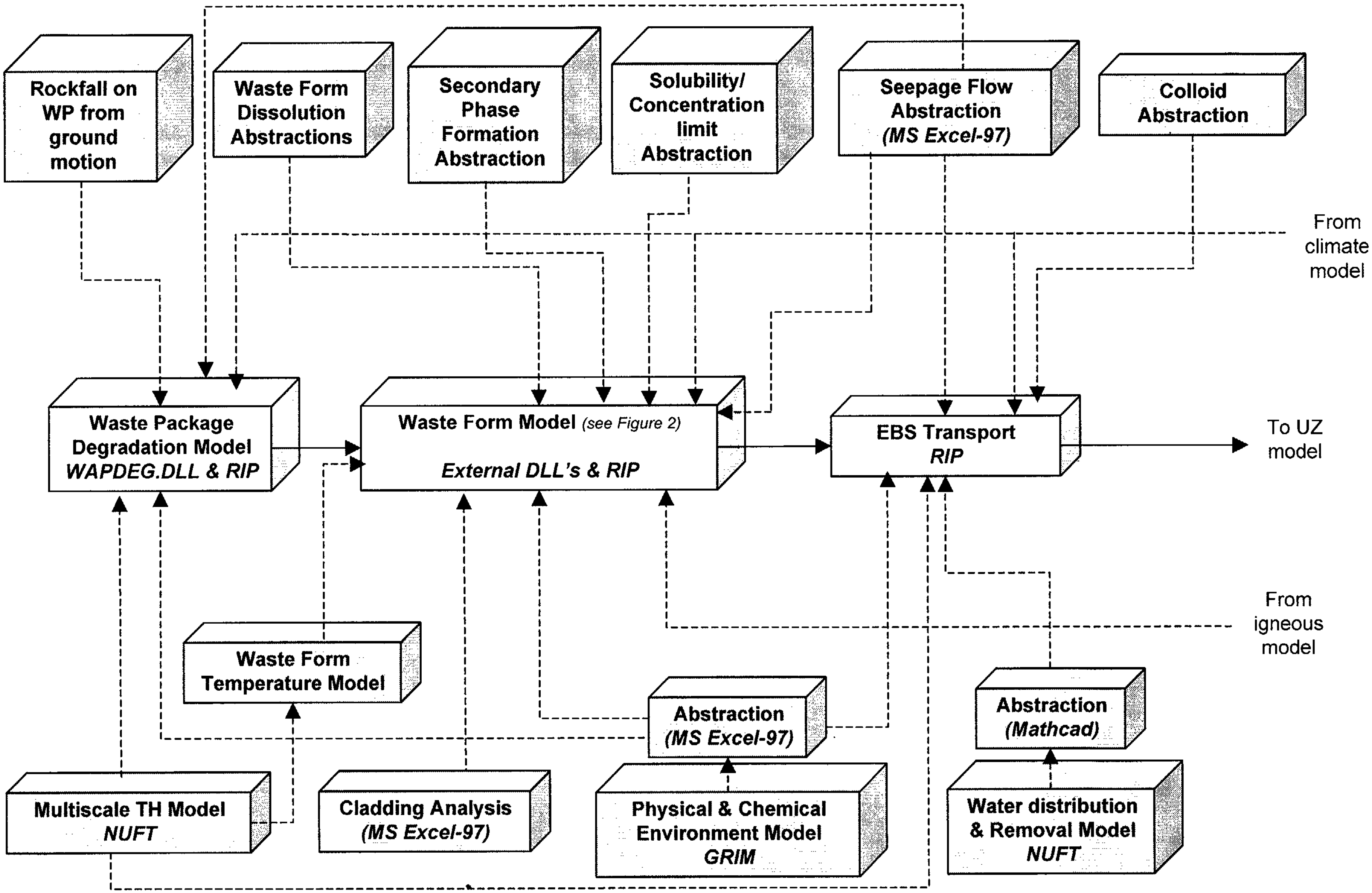


WP Corrosion (Humid Air, Aqueous, etc.)	Spatial & Temporal Distribution of Flow	Flow Rates in Water-Production Zones	**Volcanic Disruption of WPs**	Dilution of Radionuclides in Groundwater
Mechanical Disruption of WPs(Rock Falls, etc)	Distribution of Mass Flux between Matrix & Fractures	Retardation in Water-Production Zones & Alluvium	Airborne Transport of Radionuclides	Dilution of Radionuclides in Soil
Quantity & Chemistry of Water Contacting WPs & Waste Forms	Retardation in Fractures			Location & Lifestyle of Critical Group
Radionuclide Release Rates & Solubility Limits				

EBS & Waste Package Design Changes for TSPA-SR

- **Waste Package (WP) design**
  - Alloy 22 outer barrier (20 mm)
  - 316 stainless steel inner barrier (50 mm)
- **Drip shield (DS)**
  - Ti Grade 7 (20 mm) to protect WP from dripping water
  - Allows WPs to pass through "windows of susceptibility" to localized corrosion
- **Backfill/invert**
  - Quartz sand or crushed tuff ("large" grained)
    - » provide protection for drip shield and WP against rockfall
    - » protects Ti dripshield from reaction with Fe ground support
    - » diffusion barrier

Wiring Diagram for TSPA-SR EBS Models



Performance Goals of Waste Package & Drip Shield in TSPA-SR

- **Long-lived waste packages:**
  - Waste package failure is defined as an initial perforation through waste container wall (i.e., first pit penetration, first crack propagation, or first patch opening)
- **Limited radionuclide release, controlled by:**
  - Size of perforations of waste container subsequent to failure
  - Limited water flow through drip-shield/waste-package perforations for those packages contacted by seeps
  - Low invert diffusion coefficient for packages not contacted by seeps

Planned Improvements for TSPA-SR Waste-Package Model

- Models and abstractions based on Project-developed experimental data where feasible
  - More defensible process-model basis for corrosion rate abstractions and local exposure conditions, including the associated variability and uncertainty
  - Where Project data are not available, use available literature data
- Minimize use of expert elicitation

Planned Improvements for TSPA-SR Waste-Package Model

(Continued)

- **Additional degradation processes will be evaluated and incorporated in models, if warranted**
  - For Alloy 22:
    - » stress corrosion cracking (SCC)
    - » effects of phase stability and aging on localized corrosion, SCC, and rockfall damage
  - For Ti Grade-7 drip shield:
    - » SCC
    - » hydrogen-induced cracking (HIC)
- **Include effects of material/manufacturing defects and rockfall damage (if no backfill) by coupling these defects with normal corrosion processes—causes enhanced crevice/pitting corrosion and SCC**

Planned Improvements for TSPA-SR Waste-Package Model
(Continued)

- Changes to key model parameters in waste-package conceptual models, if warranted:
  - Random sampling for patch size
  - Random sampling for fraction of WP surface wetted by drips
  - Alternative conceptual models for sequence of WP barrier degradation
    - » patch by patch degradation for both barriers (VA model)
    - » entire surface of inner barrier subject to corrosion following first patch penetration of outer barrier
  - Cyclic wet and dry under dripping

Other Features of WP Model for TSPA-SR

- Because simultaneous WP/DS failures before 10,000 years are so unlikely, requires modified approach to demonstrate consequences in the probabilistic TSPA simulations, either
  - Importance sampling of early (juvenile) WP/DS failures within nominal scenario simulations, or
  - Separate scenarios for early failures
    - » the separate-scenarios time histories then averaged during post-processing with the nominal scenario (which may be zero)

Other Features of WP Model for TSPA-SR
(Continued)

- Variability and uncertainty of WP and DS degradation will be represented in WAPDEG analysis, based on the variability and uncertainty both of individual corrosion processes and of exposure conditions in the repository

Performance Goals of Waste Form in TSPA-SR

- Limited radionuclide release, controlled by:
  - Water contact
  - Degradation of Zircaloy cladding on commercial spent nuclear fuel
  - Degradation/alteration of various waste form types
  - Mobilization of radionuclides
    - » dissolution into aqueous phase (limited by solubility)
    - » attachment to mobile colloids (limited by colloid stability)
    - » gaseous phase transport
  - In-package advection/diffusion through alteration products

Planned Improvements for TSPA-SR Waste-Form Model

- Inventory & package groupings
  - Revised waste stream estimate for most fuel types
  - Possibly additional BWR/PWR source term groupings to ensure greater consistency between heat output and radioisotope inventory
  - Stainless-clad fuel rods packaged into a limited number of packages—not averaged throughout the Zircaloy-clad inventory
  - Plutonium MOX and glass waste included (distributed in HLW and CSNF packages)
  - Evaluate whether to track additional radioelements:
    - » Tc, I, Np, U, Pu, Se, Pa, and C tracked in VA
    - » reevaluate Ac, Ra, Th, Am, Pd, and Cl

Planned Improvements for TSPA-SR Waste-Form Model

- Cladding model (if credit is taken)
  - More defensible estimate of uncertainties in juvenile failure & mechanical failure distributions
  - Reevaluation of localized corrosion model, e.g., DHC
  - Improved temperature history on surface of cladding
- Waste-form matrix degradation
  - Evaluate whether to use alternative CSNF rate law (due to carbonates/silicates)
  - Improved rate equation for N-Reactor fuel (DSNF) based on recent experimental data
  - Vapor hydration model for borosilicate (HLW) glass, which could lead to higher release rates when liquid water is able contact waste

Planned Improvements for TSPA-SR Waste-Form Model

- Dissolved concentration limits
  - Replace 1993 expert-elicitation pure-phase concentration limits ("solubilities") with more recent NEA data, literature data, and Project experiments
  - Revision of mixed-phase concentration limits based on experimental observations—extension of lower bound of Np concentration distribution (secondary phases)

Planned Improvements for TSPA-SR Waste-Form Model

(Continued)

- Colloids
  - In addition to Pu, consider Am
  - More defensible relationship for colloid concentration
  - Incorporate newly available experimental data for reversible sorption/desorption on colloids
  - For irreversible sorption use new desorption test data as conservative upper bound to Benham test data
- In-package transport: see EBS transport

“Performance Goals” of EBS Transport & In-Drift Geochemical Environment (IDGE) in TSPA-SR

- Limited water contact, controlled by
  - Dripshield
  - Backfill
- Long-lived waste packages and drip shields, controlled by
  - Favorable chemical environment
- Limited radionuclide release, controlled by:
  - Favorable chemical environment
  - Slow transport through invert

Planned Improvements for TSPA-SR IDGE/EBS Model

- Chemical composition model of seepage water flowing through backfill, as it affects drip shield degradation
- Effect of salt buildup on WP/DS corrosion
  - lowers vapor pressure and causes condensation of water on WP at higher temperatures
  - Experiments currently being conducted at various T
- Better experimental basis & model for flow diversion in the drift (1/4-scale model)
  - Fraction of drift seepage entering DS
  - Fraction of DS seepage entering WP

Planned Improvements for TSPA-SR IDGE/EBS Model

(Continued)

- In-package chemical environment
  - Feeds WP inside-out corrosion
  - Different chemical environment inside HLW & DSNF waste packages compared to CSNF, if warranted
- In-package transport (if credit is taken)
  - In-package hydrology model, fraction of waste-form surface contacted by advecting water
  - In-package evaporation—no transport out of the WP until liquid can form
  - Basket degradation and waste-form settling
  - In-package sorption—types of degradation phases, linear vs. nonlinear models, available sites

Planned Improvements for TSPA-SR IDGE/EBS Model

(Continued)

- THC model of flow and transport within invert
  - Diffusion coefficient in a non-concrete invert (a function of saturation, which is a function of flux)
  - Physical/chemical property changes in the invert due to precipitation/dissolution (i.e., permeability changes)

Planned Improvements for TSPA-SR IDGE/EBS Model

(Continued)

- Major uncertainties/variabilities to be quantified
  - Flow diversion uncertainty through DS and WP (based on experiments)
  - Boundary-condition uncertainty on the chemical composition of water entering drift
    - from UZ far-field flow and transport model (one chemical composition per flow field, probably 12 total)
  - Repository-scale variability in temperature, relative humidity, and infiltration

Planned Bounding Assumptions for TSPA-SR IDGE Models

- Set of reactions simplified in a conservative sense
- Choose equilibrium over kinetic, where bounding and where data is limited
- Conservative corrosion rates for package internals
- Normative salt approach because no thermodynamic data available for high ionic-strength solutions in the presence of carbonates and silicates

Quality Assurance

- Process-level models and data and their abstractions, including associated software, will be documented and controlled in accordance with applicable procedures, e.g., AP-3.10Q, YAP-SIII.3Q, and AP-SI.1Q
- Fully qualified version of WAPDEG (version 4.0) through AP-SI.1Q
- Coupling of TSPA model (WINRIP) and WAPDEG to facilitate TSPA uncertainty analysis and to improve data traceability & control

Quality Assurance
(Continued)

- Qualified IDGE code (GRIM)
  - Connected flow-through geochemical mixing cells
  - Traceability, control, reproducibility, documentation
- Qualified data for concentration limits

Summary

- Important drivers for changes from VA to SR/LA:
  - Quality assurance
  - New repository and waste-package/drip-shield design
  - New regulations (proposed 10 CFR 63; 40 CFR 197 when out)
- New data for several models (notably waste-package degradation, water diversion around DS/WP, and colloids)

Summary
(Continued)

- Planned improvements to engineered barrier models if warranted, e.g., for WP degradation, radionuclide concentration limits, EBS flow and transport, in-drift geochemical environment
- Bounding models/assumptions for some FEPs