A Simplified Performance Assessment (PA) Model for Radioactive Waste Disposal Alternatives

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What a Simplified Performance Assessment Model is NOT

- NOT a complex representation of highly coupled thermal-hydrologic-chemical-mechanical-biological-radiological (THCMBR) processes
- NOT sufficient to represent highly site-specific phenomena and scenarios based on detailed experimental data
- NOT sufficient to support a repository license application
Why Develop a Simplified Performance Assessment Model?

- The U.S. repository program is currently re-considering a number of long-term disposal alternatives
  - Combinations of waste form types
    - used/spent nuclear fuel (UNF)
    - high-level waste (HLW) – glass, ceramic, metal
  - and concepts/settings
    - mined geologic disposal in clay/shale, salt, and granite/hard rock
    - deep borehole disposal
- Need fast and flexible PA capabilities for generic scoping studies of these alternatives
  - Order of magnitude performance estimates are sufficient
- A simplified model isolates/emphasizes key phenomena
  - Can provide more focused insights to system performance
  - Does not rely on overly complex processes and/or couplings that may be difficult to parameterize/quantify
Why Develop a Simplified Performance Assessment Model? (cont.)

- Most long-term radioactive waste disposal PAs are controlled by a few key processes/parameters
  - Duration of radionuclide releases from waste packages (WPs) (fast vs. slow)
    - Waste form (WF) and WP degradation rates, radionuclide solubility
  - Transport processes/residence time in the engineered barrier system (EBS) and in the natural system / geosphere
    - Advection, diffusion, sorption, decay
## Generic Disposal System Conceptual Model

- 1-D schematic representation of generic system domains and phenomena common to most disposal system alternatives
  - Based on feature, event, and process (FEP) identification

### Table: Generic Disposal System Conceptual Model

<table>
<thead>
<tr>
<th></th>
<th>NEAR FIELD</th>
<th>FAR FIELD</th>
<th>RECEPTOR</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SOURCE</strong></td>
<td>ENGINEERED BARRIER SYSTEM (EBS)</td>
<td>GEOSPHERE</td>
<td>BIOSPHERE</td>
</tr>
<tr>
<td><strong>Waste Form</strong></td>
<td>Waste Package</td>
<td>EBS Region (e.g., buffer, backfill, liner, seals)</td>
<td>Host Rock and Other Geologic Units</td>
</tr>
<tr>
<td>[UNF] [HLW]</td>
<td>[BENTONITE BUFFER]</td>
<td>[GRANITE]</td>
<td>[CLAY/SALT]</td>
</tr>
<tr>
<td></td>
<td>[CLAY, SALT BACKFILL]</td>
<td></td>
<td>[SALT]</td>
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<tr>
<td></td>
<td>[DEEP BOREHOLE SEAL]</td>
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### Diagram: Simplified THCMBR Processes

- Radionuclide Transport

### Table: Simplified THCMBR Processes

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<thead>
<tr>
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<th>EBS Environment</th>
<th>Geosphere Environment</th>
<th>Biosphere Environment and Dose Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Source Term</strong></td>
<td>EBS Transport</td>
<td>Geosphere Transport</td>
<td>Biosphere Transport</td>
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</tbody>
</table>
Simplified PA Model – Repository Representation

- **Geometry / configuration**
  - dimensions, number of tunnels, tunnel spacing, number of WPs, WP spacing, orientation (horizontal/vertical)

- **Transport pathways**
  - number of pathways, pathway cross-sectional area, number of WPs per pathway
Simplified PA Model –
Source Representation

- Radionuclide release from waste package to EBS
  - Advective (driven by thermal or gas-generation induced pressure gradients) and/or
  - Diffusive (driven by source concentrations)

- Waste properties (temperature and chemistry dependent)
  - initial radionuclide inventory, waste form geometry and degradation rates, waste package geometry and failure times, radionuclide solubilities

![Diagram of simplified THCMBR processes](image-url)
Simplified PA Model – Near Field Representation

- Radionuclide transport through EBS components (e.g., buffer, backfill) and near field geology (EDZ, durably affected host rock)
  - EBS - advective (e.g., fast paths, crushed rock) and/or diffusive (e.g., bentonite)
  - Host Rock - advective (e.g., granite/EDZ fractures) and/or diffusive (e.g., clay/shale)

- Flow and transport properties in EBS components and near field geology
  - flow path geometry, gradients, permeability, porosity, dispersivity, diffusivity, $k_d$s, ...
  - parameter values based on generic material properties
Radionuclide transport through far field geology (host rock, adjacent aquifer)
- Host Rock - advective (e.g., granite, salt interbeds) or diffusive (e.g., clay/shale)
- Aquifer - highly advective with possible mixing/dilution

Flow and transport properties in far field geology
- flow path geometry, gradients, permeability, porosity, dispersivity, diffusivity, $k_d$s, ...
- parameter values based on generic material properties

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<th>FAR FIELD</th>
<th>RECEPTOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENGINEERED BARRIER SYSTEM (EBS)</td>
<td>EBS Region (e.g., buffer, backfill, liner, seals)</td>
<td>Host Rock and Other Geologic Units</td>
<td>Surface and Biosphere</td>
</tr>
<tr>
<td>Waste Form [UNF] [HLW]</td>
<td>[BENTONITE BUFFER] [CLAY, SALT BACKFILL] [DEEP BOREHOLE SEAL]</td>
<td>[GRANITE] [CLAY/SHALE] [SALT]</td>
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<td>Waste Package</td>
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Simplified THCMBR Processes

**Radionuclide Transport**
- EBS Environment
  - Source Term
  - EBS Transport
- Geosphere Environment
  - Geosphere Transport
- Biosphere Environment and Dose Factors
  - Biosphere Transport
Simplified PA Model – Biosphere Representation

- Groundwater withdrawal from aquifer to receptor

- Biosphere properties
  - withdrawal well pumping rate (radionuclide mass flux to surface)
  - dose conversion factors (based on receptor lifestyle / water usage / consumption rate)
  - parameter values based on IAEA 2003 Example Reference Biosphere (ERB) 1B
**Simplified PA Model Results – Clay/Argillite**

**ANDRA Conceptual Model (ANDRA Dossier 2005: Argile)**

**Source**
- 13,500 UNF WPs
- WP failure time = 10,000 yrs
- WF degradation rate = $2 \times 10^{-5}$ yr$^{-1}$, (gradual releases over 50,000 yrs)
- Radionuclide specific solubilities
- Diffusive releases from WPs

**Near Field**
- Bentonite / EDZ argillite (5 m)
- Diffusion-dominated transport
- Radionuclide specific diffusion coefficients and retardation factors

**Far Field**
- Callovo-Oxfordian (COX) argillite (60 m)
- Diffusion-dominated transport
- Radionuclide specific diffusion coefficients and retardation factors

**Biosphere**
- Pumping well in the permeable formation overlying the Callovo-Oxfordian discharges to the Saulx Valley
- Pumping rate = 100 L/min
- BDCFs representative of a farming community

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ANDRA Dossier 2005, Figure 5.3-11

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Simplified PA Model Results – Clay/Argillite

- Annual Dose (at Saulx Outlet)

ANDRA Dossier 2005, Figure 5.5-18

Simplified PA Model
Simplified PA Model Results – Clay/Argillite

- $^{129}I$ Mass Flux from the Callovo-Oxfordian (COX) host rock

ANDRA Dossier 2005, Figure 5.5-2

Simplified PA Model
Simplified PA Model Results – Deep Borehole


**Source**
- 400 UNF WPs in a 2 km source zone
- WP failure time = 0 yrs
- WF degradation rate = $1 \times 10^{-7}$ yr$^{-1}$, (min = $1 \times 10^{-8}$ yr$^{-1}$, max = $1 \times 10^{-6}$ yr$^{-1}$)
- Advective releases from source zone due to thermal expansion and buoyancy

**Near Field**
- Bentonite/clay seal zone (1000 m)
- Advective and diffusive transport
- RN specific diffusion coeffs and $k_d$s

**Far Field**
- Sediments/aquifer (2000 m)
- Advective transport with sorption

**Biosphere**
- Pumping well in the far field
- Dilution (pumping) rate = 10,000 m$^3$/yr
- BDCF$s$ representative of IAEA ERB1B
Simplified PA Model Results – Deep Borehole

Mean Annual Dose

UNF high perm., no I sorption

Sensitivity to perm. and I sorption

UNF base permeability, no I sorption
UNF base permeability, seal I sorption
UNF high permeability, no I sorption
UNF high permeability, seal I sorption
Simplified PA Model - Summary

- Fast and flexible PA capabilities for generic scoping studies of disposal system alternatives
  - Utilizes common domains (Source, Near Field, Far Field, Biosphere)
  - Can be applied to a range of WFs (e.g., UNF, HLW) and concepts/settings (e.g., mined clay, salt, or granite, deep borehole)

- Simplified model controlled by a few key processes/parameters
  - Isolates key phenomena
    - temporal evolution of radionuclide releases from source term
    - transport in near field and far field
  - Provides for:
    - focused insights to system performance
    - sensitivity studies

- Simplified framework is modular, complexity in process representation can be added in specific domains as needed