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

Geoff Freeze and Joon Lee

Sandia National Laboratories

IHLRWM Conference, Albuquerque, NM

April 13, 20011

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. SAND2011-2367C

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**

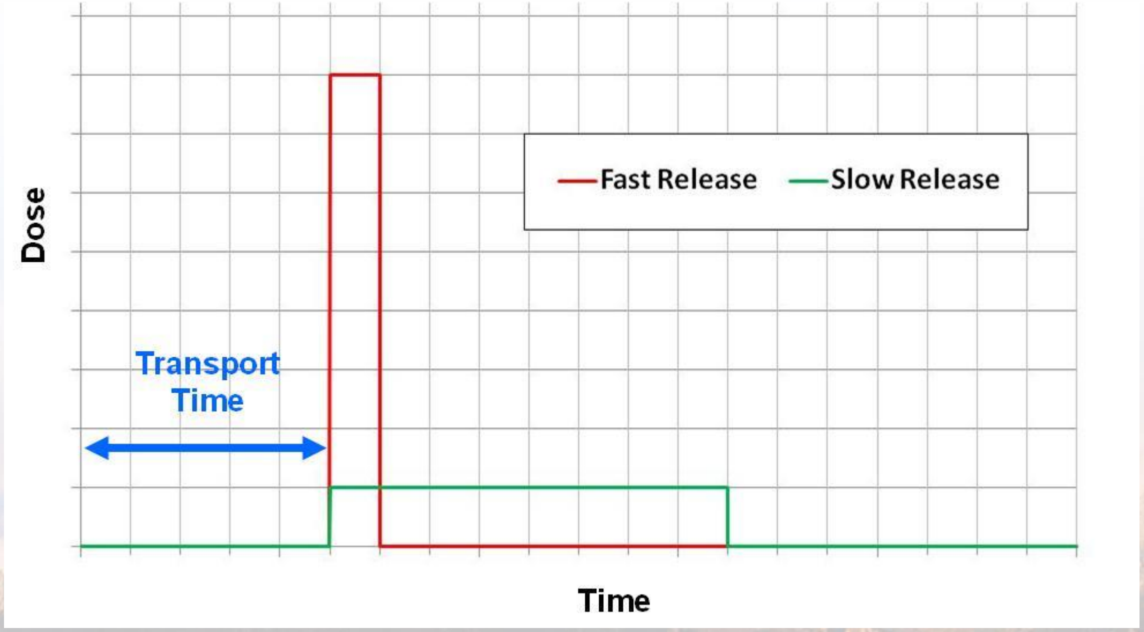
- **NOT sufficient to support a repository license application**

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

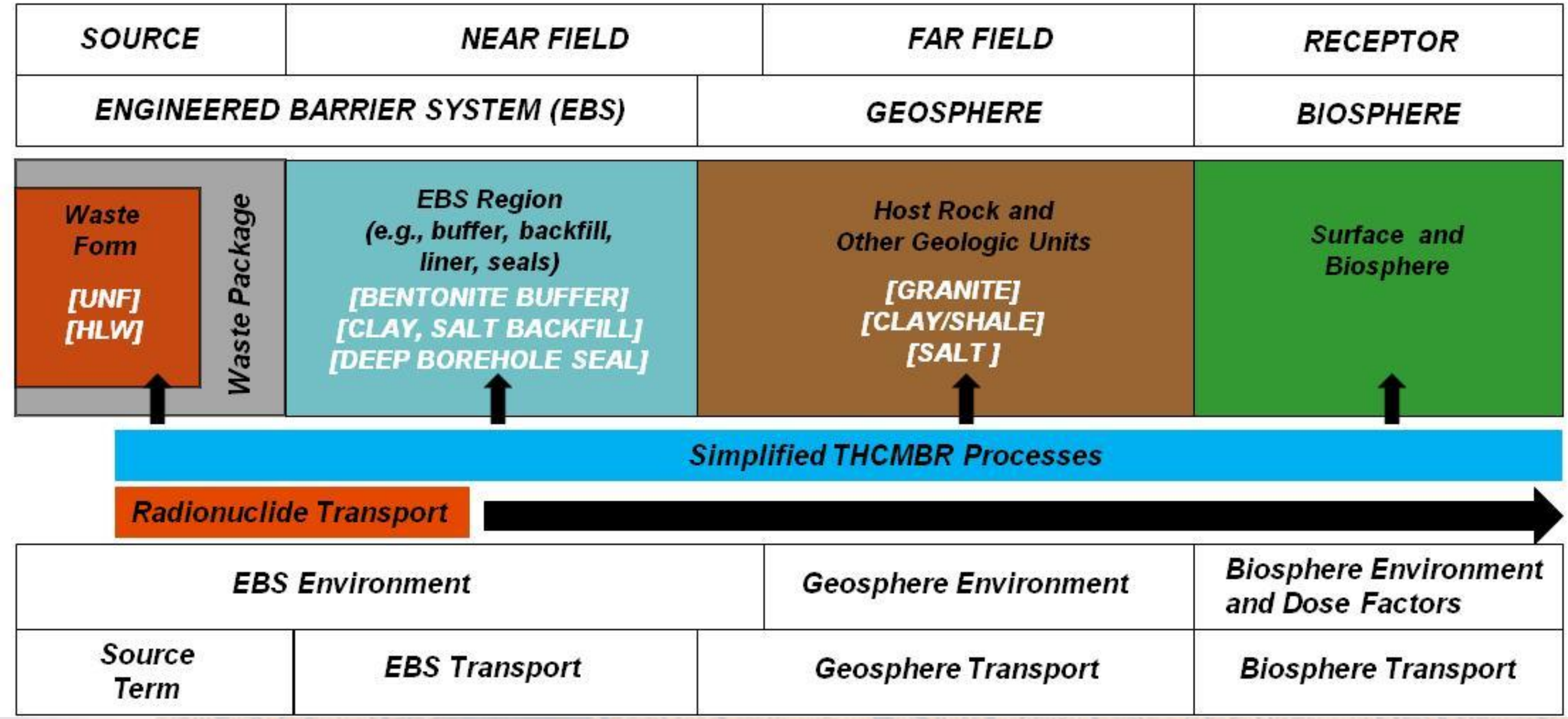
Why Develop a Simplified Performance Assessment Model? (cont.)

- **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



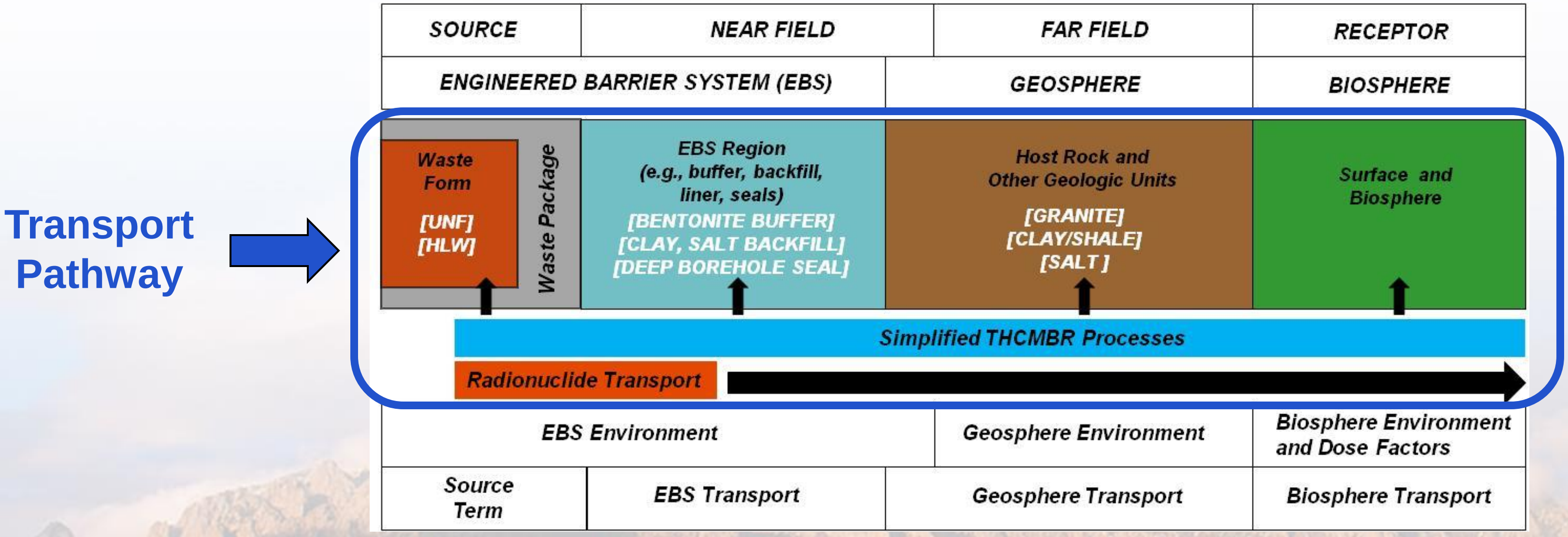
Generic Disposal System Conceptual Model

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



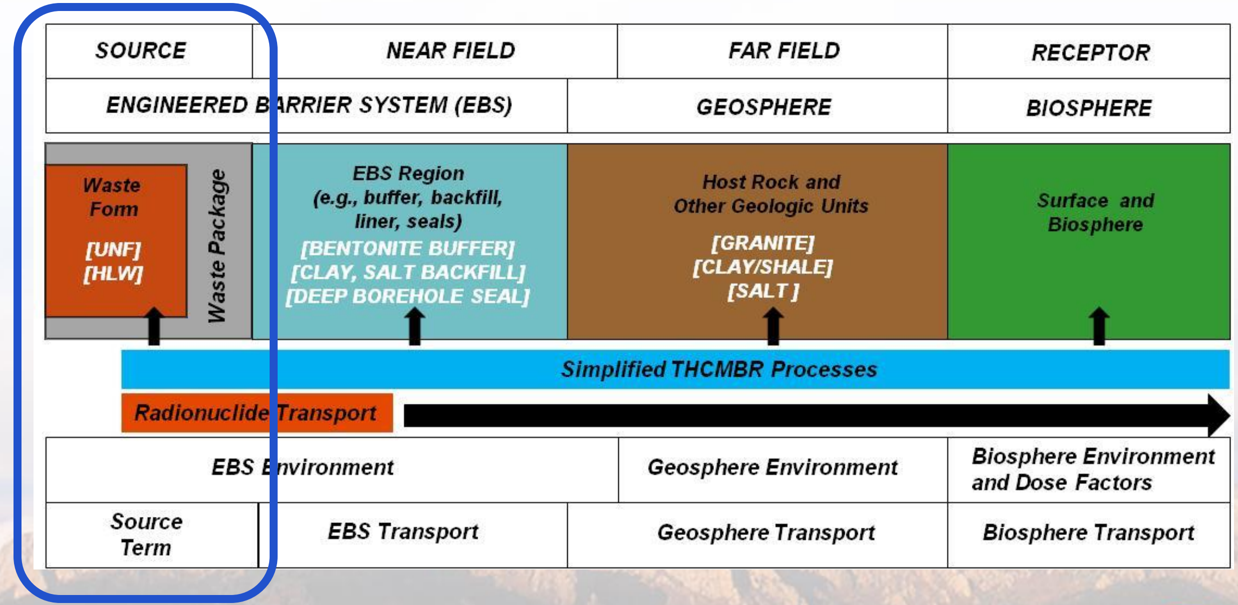
Simplified PA Model – Repository Representation

- **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



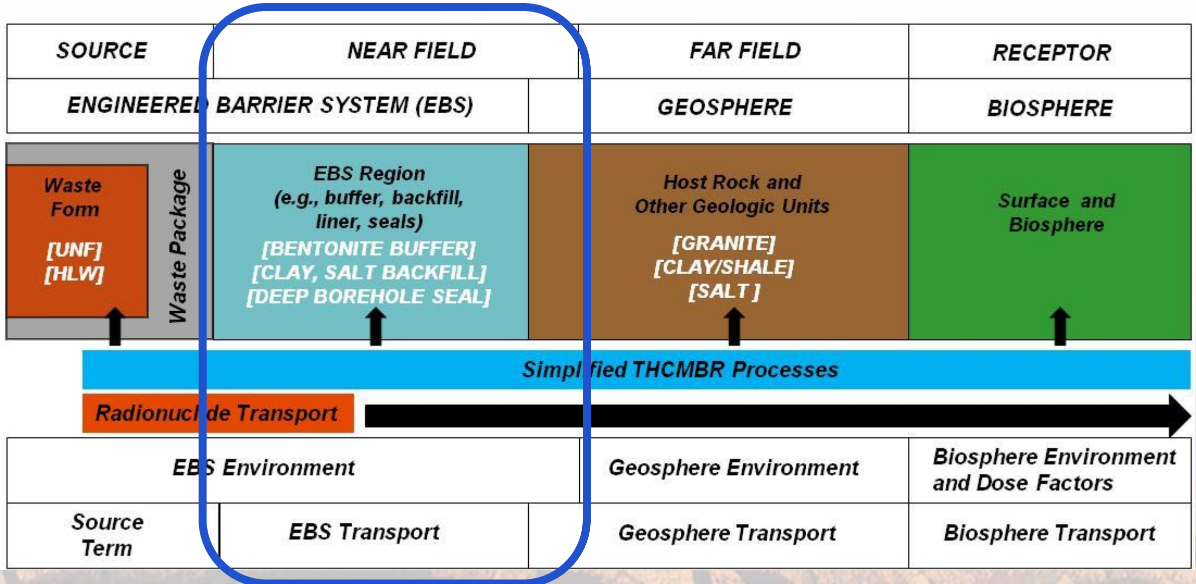
Simplified PA Model – Source Representation

- **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



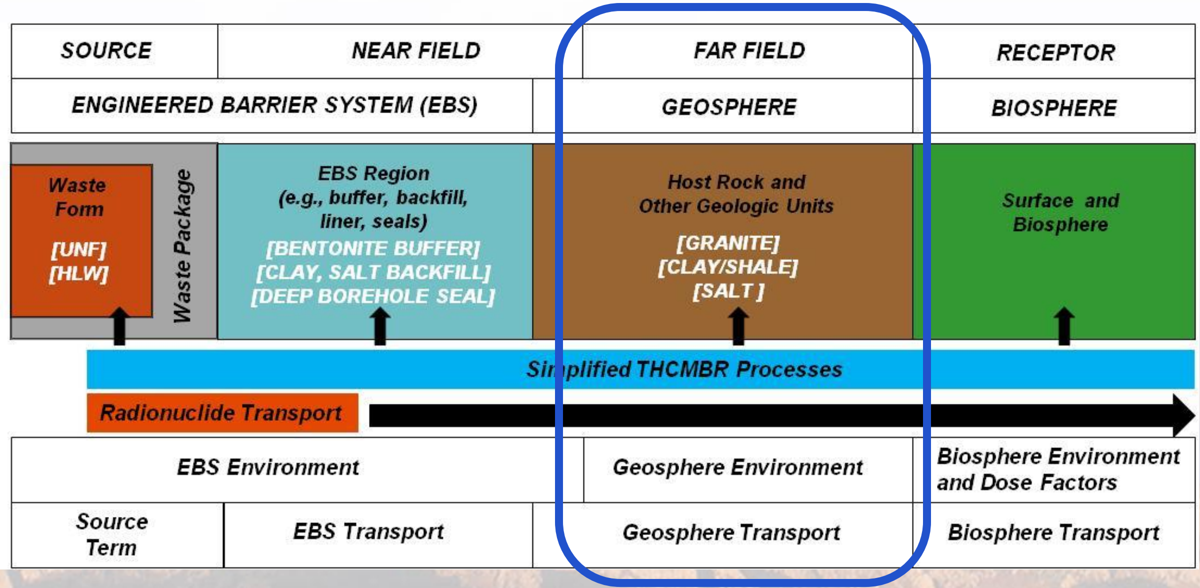
Simplified PA Model – Near Field Representation

- **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_ds, …
  - parameter values based on generic material properties



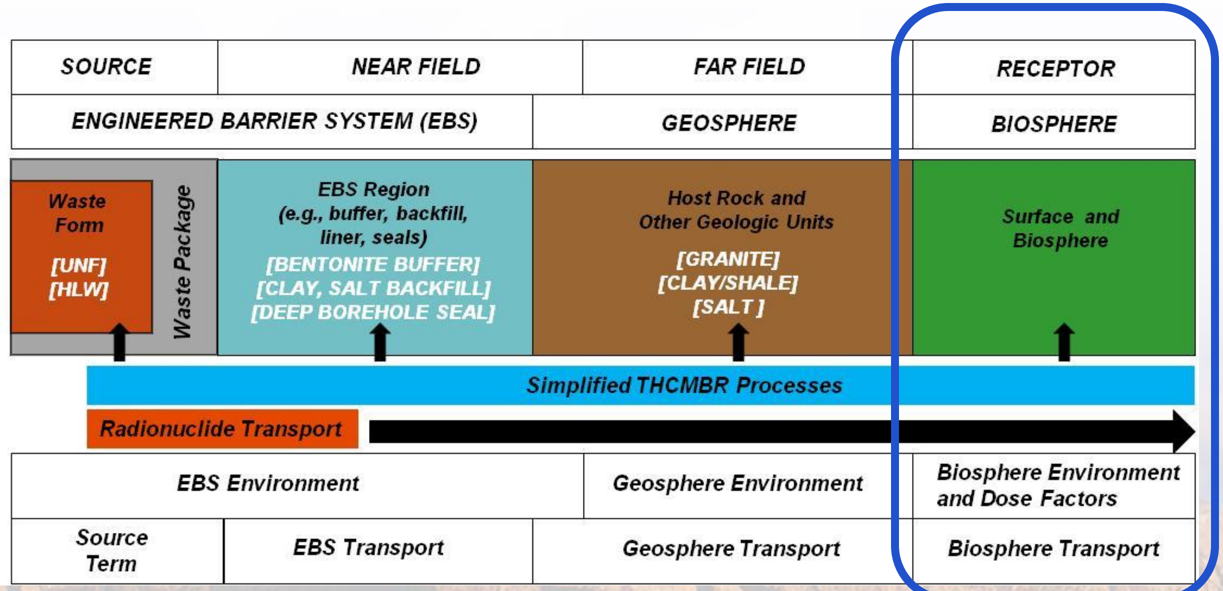
Simplified PA Model –
Far Field Representation

- **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_ds, …
  - parameter values based on generic material properties



Simplified PA Model – Biosphere Representation

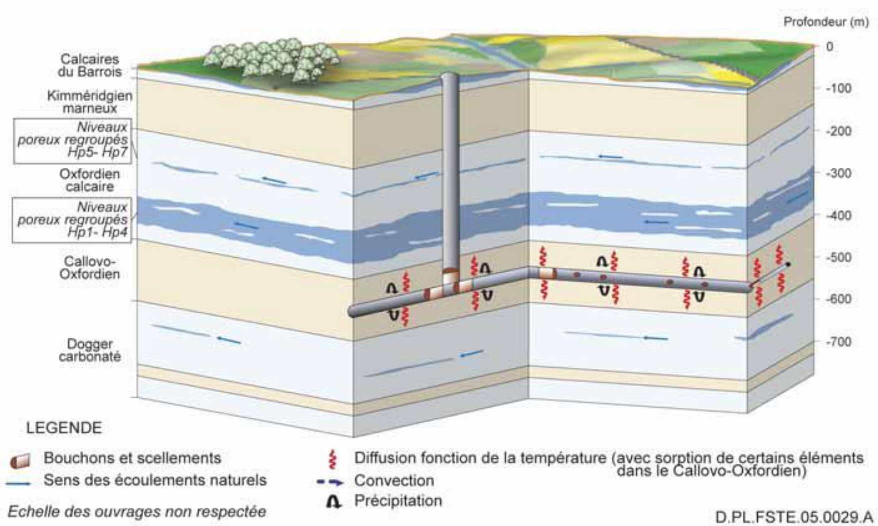
- **Groundwater withdrawal from aquifer to receptor**
- **Biosphere properties**
  - withdrawal well pumping rate (radionuclide mass flux to surface)
  - dose conversion factors (based on receptor lifestyle / water usage / consumption rate)
  - parameter values based on IAEA 2003 Example Reference Biosphere (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 = 2×10^{-5} yr^{-1}, (gradual releases over 50,000 yrs)
  - Radionuclide specific solubilities
  - Diffusive releases from WPs

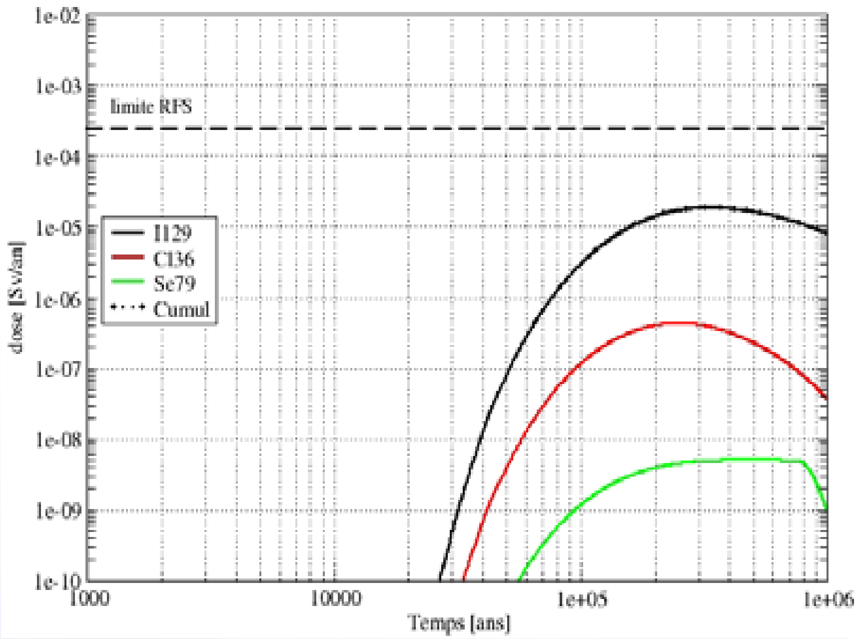


ANDRA Dossier 2005, Figure 5.3-11

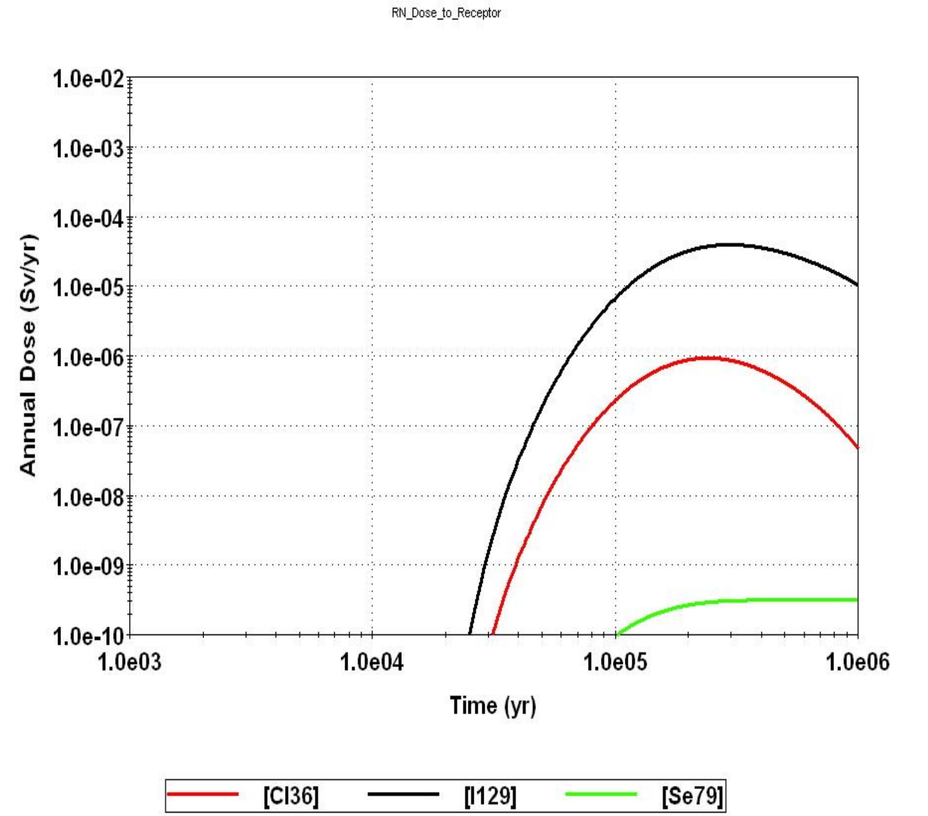
- **Near Field**
  - Bentonite / EDZ argillite (5 m)
  - Diffusion-dominated transport
  - Radionuclide specific diffusion coefficients and retardation factors
- **Far Field**
  - Callovo-Oxfordian (COX) argillite (60 m)
  - Diffusion-dominated transport
  - Radionuclide specific diffusion coefficients 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

Simplified PA Model Results – Clay/Argillite

- **Annual Dose (at Saulx Outlet)**



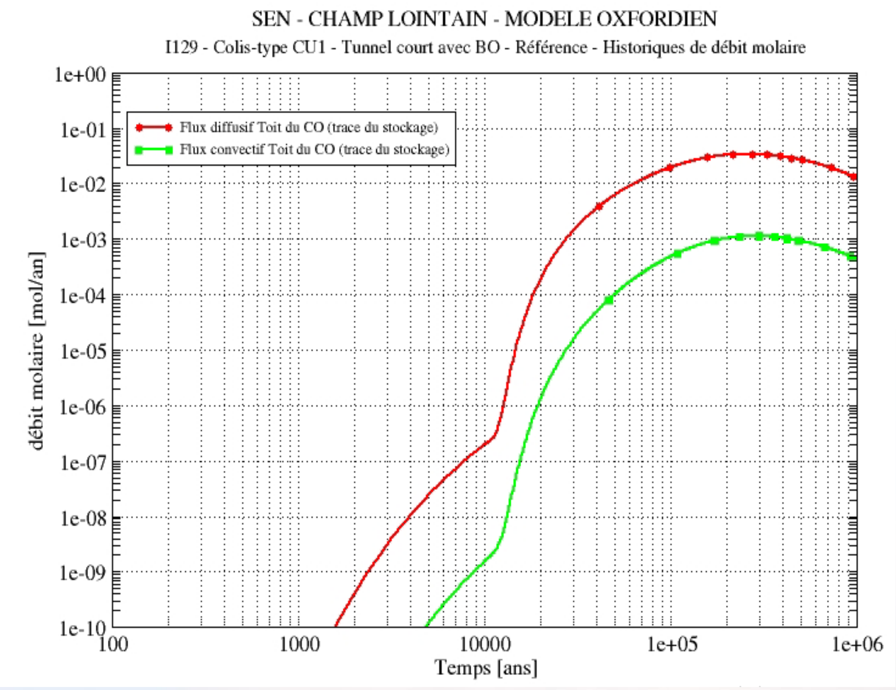
ANDRA Dossier 2005, Figure 5.5-18



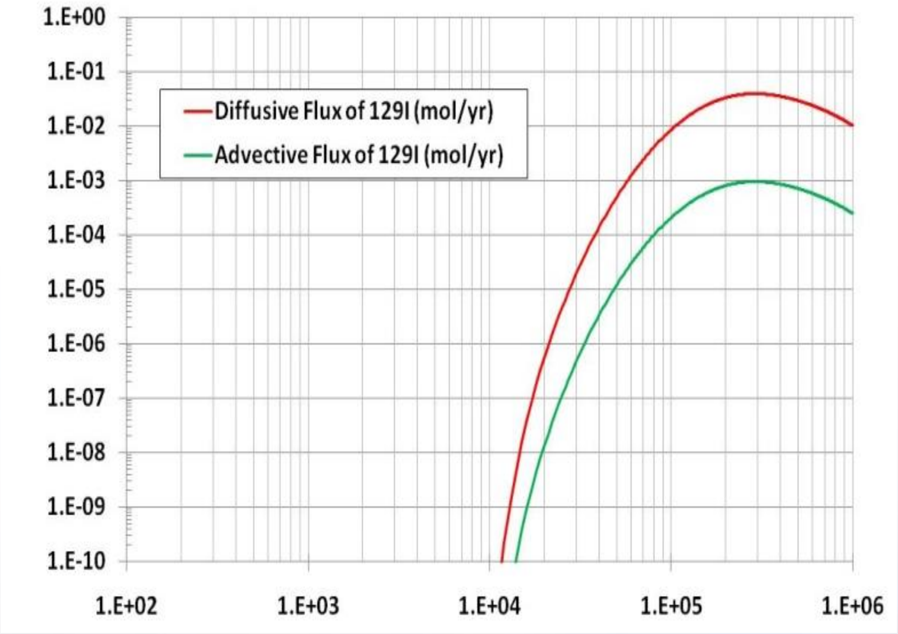
Simplified PA Model

Simplified PA Model Results – Clay/Argillite

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



ANDRA Dossier 2005, Figure 5.5-2

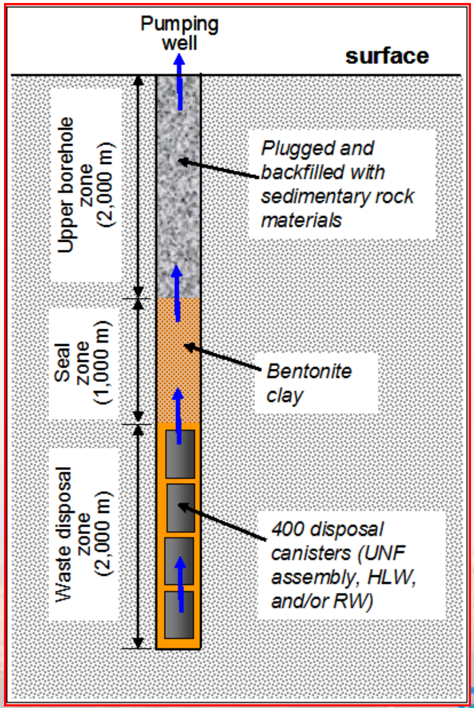


Simplified PA Model

Simplified PA Model Results – Deep Borehole

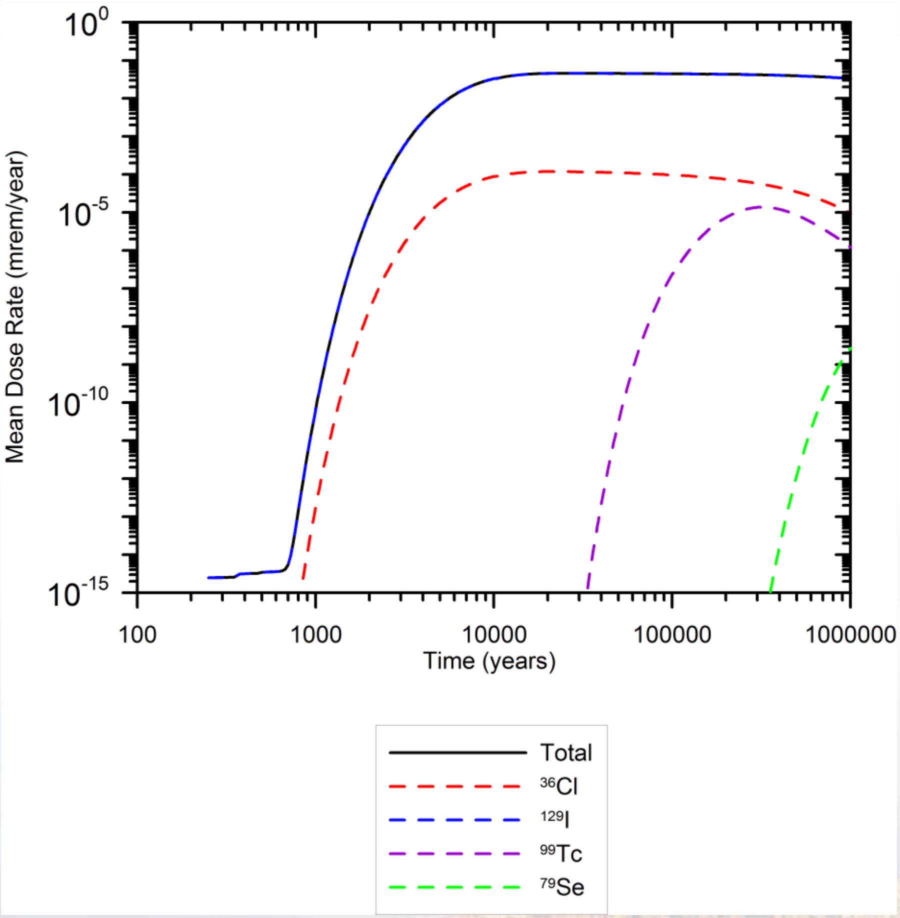
- **Sandia National Labs Conceptual Model (SAND 2009-4401: Brady et al. 2009; IHLRWMC: Swift et al. 2011)**

- **Source**
  - 400 UNF WPs in a 2 km source zone
  - WP failure time = 0 yrs
  - WF degradation rate = $1x10^{-7}$ yr^{-1}, (min = $1x10^{-8}$ yr^{-1}, max = $1x10^{-6}$ 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_ds
- **Far Field**
  - Sediments/aquifer (2000 m)
  - Advective transport with sorption
- **Biosphere**
  - Pumping well in the far field
  - Dilution (pumping) rate = 10,000 m3/yr
  - BDCFs representative of IAEA ERB1B

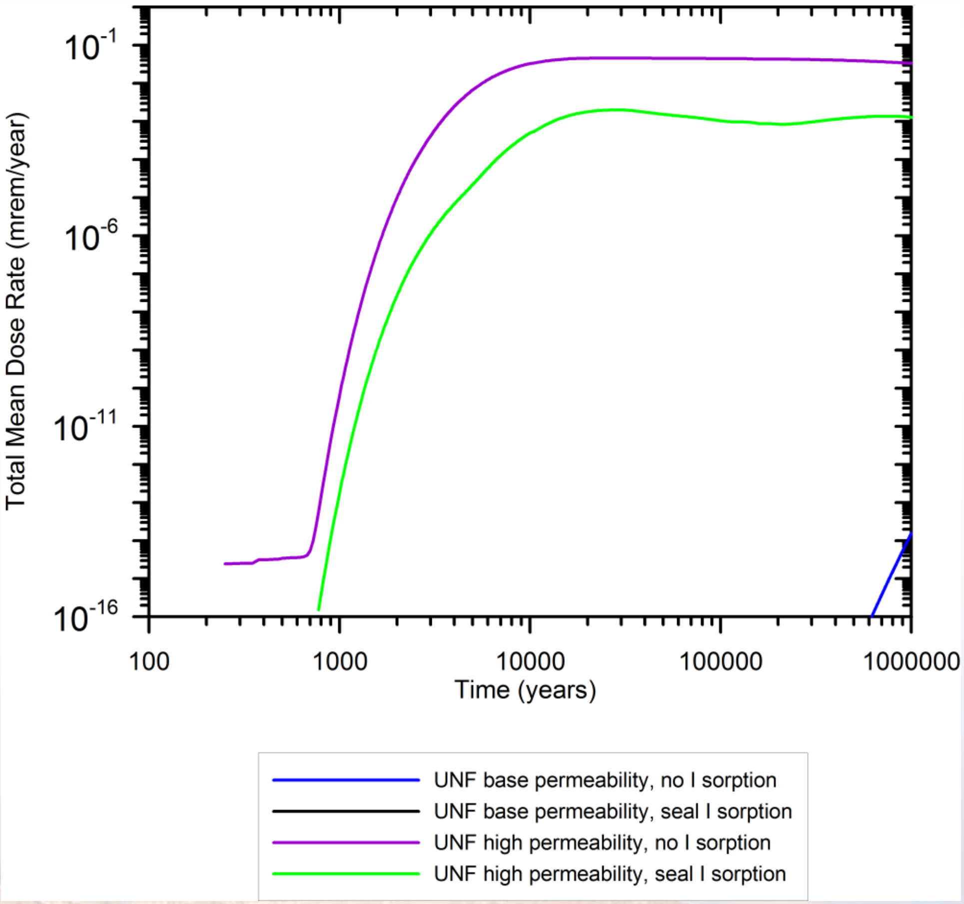


Simplified PA Model Results – Deep Borehole

- **Mean Annual Dose**



UNF high perm., no I sorption



Sensitivity to perm. and I sorption

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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**