A Performance Assessment Model for Generic Repository in Salt Formation

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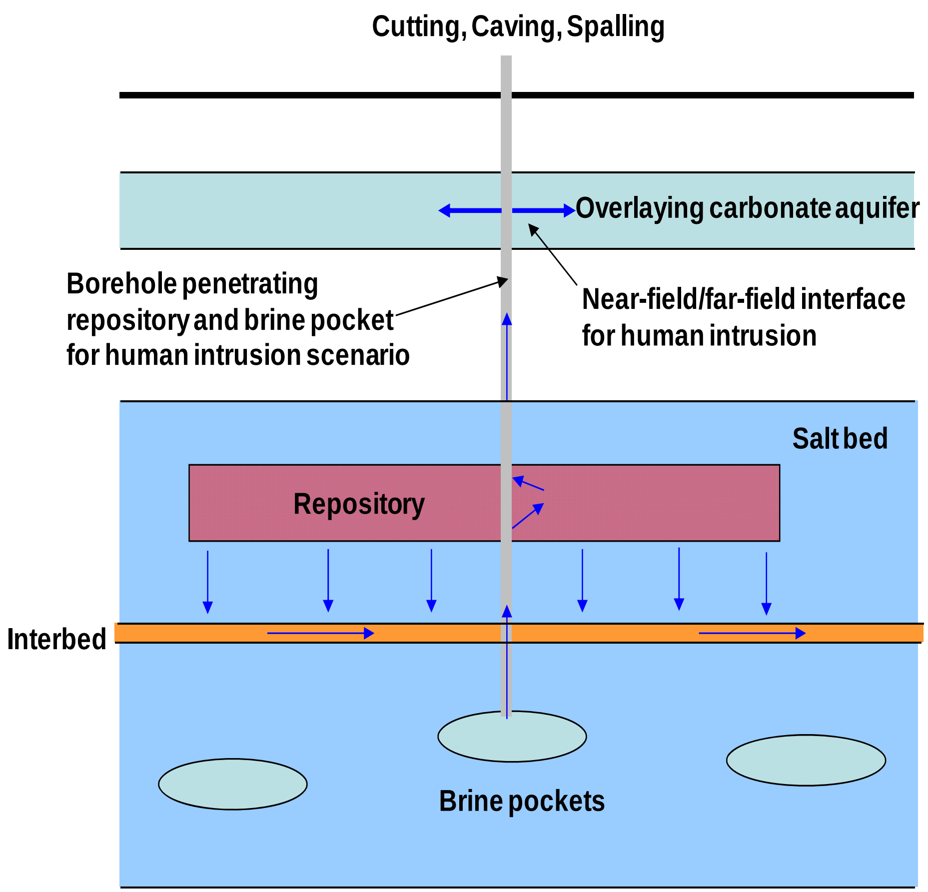
Outline

- Introduction
- Conceptual model
- Waste inventories and scenarios
- Radionuclide (RN) mobilization and transport
- Model results
- Summary and conclusions
- Future work

Introduction

- Salt repository is one of four generic disposal system environment (GDSE) options currently under study by U.S. DOE
  - Stable geology
  - Chemically reducing condition
  - Self-healing by creep deformation
  - Limited water availability and movement
- The salt GDSE study is to support the development of a long-term strategy for geologic disposal of high-level radioactive waste in a salt formation
- The immediate goal is to develop the necessary modeling tools to evaluate and improve understanding on the repository system response and relevant processes
- This paper presents an initial version of the salt GDSE model and the model results

Conceptual Model



- Assume saturated, reducing condition
  - Repository in a bedded salt formation below a carbonate aquifer
- Isothermal condition at ambient temperature
- Undisturbed (or Reference) Scenario
  - RNs released into and transported in an interbed (1 m thick) below repository
- Disturbed Scenario
  - "stylized" human intrusion scenario
  - A single borehole penetration at 1,000 years
  - Sample the number of affected waste packages (WPs) (between 1 and 5)
  - RNs from affected WPs released directly to overlying aquifer by pressurized brines with steady-state flow rates
  - Not consider potential dose impacts of waste brought up by drilling activities

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Waste Inventories and Scenarios

- **Waste types**
  - **Commercial used nuclear fuel (UNF) (140,000 MTU)**
    - **Convert the total inventory to equivalent pressurized water reactor (PWR) inventory for simplification**
    - **32,154 UNF WPs (10 assemblies per WP)**
    - **Isotope inventory based on the PWR UNF**
      - **60 GWd/MTHM burn-up**
      - **4.73% enrichment**
      - **30 yrs after discharge from reactor**
  - **Vitrified existing DOE high-level radioactive waste (HLW)**
    - **5,003 WPs (5 canisters per WP)**
  - **Vitrified "hypothetical" reprocessing HLW of commercial UNF**
    - **99% recovery of U and Pu from commercial UNF**
    - **Assume all others remain in the waste stream**
    - **Assume the same RN mass and isotope inventory per canister as DOE HLW**
    - **4,055 WPs (5 canisters per WP)**

Waste Inventories and Scenarios

(continued)

- **Assume a square repository footprint**
  - Spacing between emplacement tunnels: 25 m
  - Spacing between WPs: 6 m
- **Waste inventory cases for Undisturbed Scenario**
  - Case 1: UNF plus DOE HLW
    - A total of 37,157 WPs
    - A square repository footprint with a side of 3,270 m
  - Case 2: DOE HLW plus reprocessing HLW
    - A total of 9,058 WPs
    - A square repository footprint with a side of 1,615 m
- **Waste inventory cases for Disturbed Scenario**
  - Case 1: assume only UNF WPs affected
  - Case 2: assume only DOE HLW WPs affected

Radionuclide Mobilization and Transport

- **Not consider WP containment barrier performance**
  - **Waste form degradation and RN release at the beginning of simulation**
  - **Treat the WP interior as porous medium of corrosion products of WP, internal components and waste form**
- **Fractional degradation rate model for waste form degradation**
  - **Commercial UNF: log-triangular: min = 10^{-8}/yr, mode = 10^{-7}/yr, max = 10^{-6}/yr**
  - **Glass waste form: log-uniform: min = 3.4×10^{-6}/yr, max = 3.4×10^{-3}/yr**
- **Model the repository disposal area as a large mixing cell**
  - **Not consider RN sorption on corrosion products and geologic materials**
- **Radio-element solubility for two redox conditions**
  - **Near-field brines (reducing condition)**
  - **Far-field brines (less reducing or slightly oxidizing condition)**

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Radionuclide Mobilization and Transport
(continued)

- RN sorption in the near-field and far-field transport
  - Linear equilibrium sorption (Kd) model for interbed and overlying carbonate aquifer
- Pore flow velocity in interbed
  - Log-uniform (10^{-8} m/yr, 2×10^{-2} m/yr)
- Pore flow velocity in overlying carbonate aquifer
  - Log-uniform (3.1×10^{-3} m/yr, 31 m/yr)
- Performance measure matrix
  - Mean mass flux from major system components (e.g., near-field and far-field boundaries)
  - Mean dose at “hypothetical” accessible environment (AE)
    - 5 km down-gradient from the edge of repository
    - IAEA BIOMASS Example Reference Biosphere 1B (ERB1B) dose model
    - Dilution rate of 1×10^4 m^3/yr in aquifer
    - Individual water consumption rate of 1.2 m^3/yr

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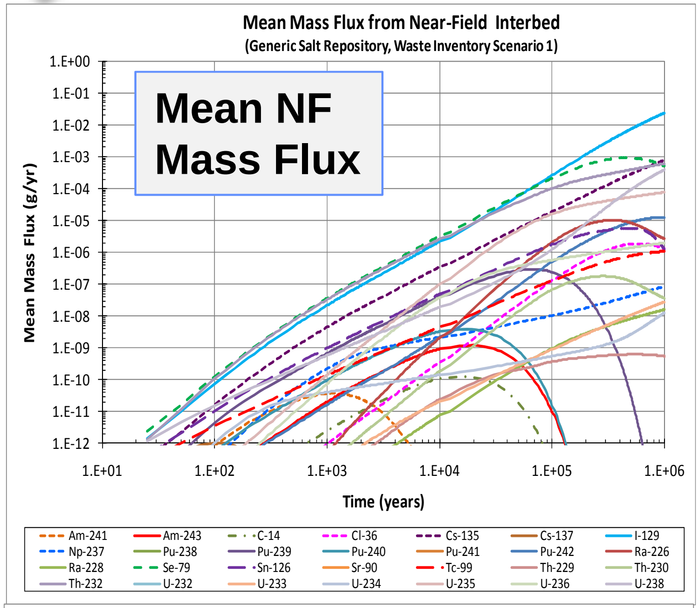
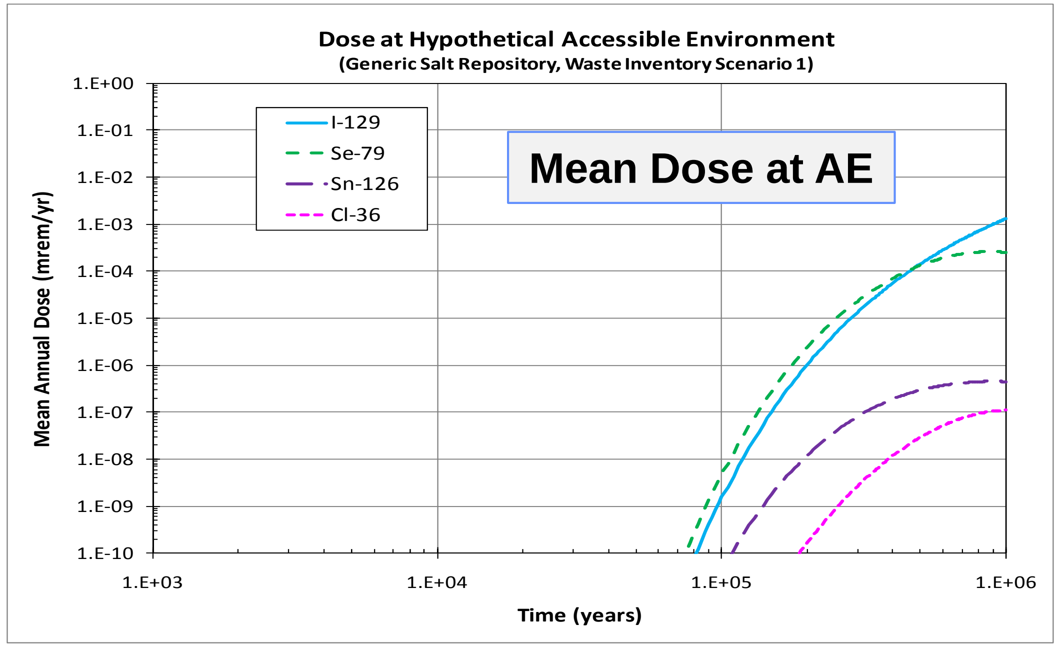
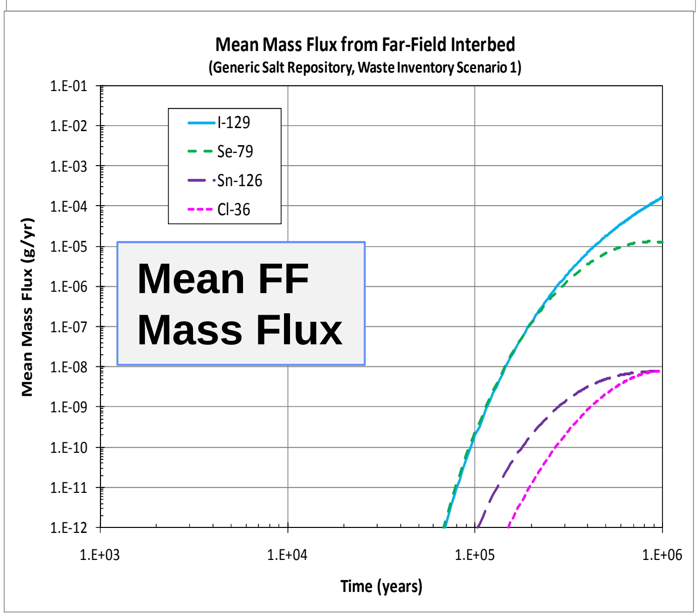
Major Conservative Bounding Assumptions

- Not consider RN release delays during initial dry-out period around the waste disposal area due to waste decay heat
  - The extent and duration of dry-out depending on repository thermal loading, WP heat output characteristics, repository thermal-hydrologic response
- No containment barrier performance of waste package
- No RN sorption on corrosion products and geologic materials in the mixing cell representing waste disposal area
- Continuous brine flow from waste disposal area to underlying interbed for the entire simulation period (Undisturbed Scenario)
- Continuous steady-state upward brine flows through the borehole for the entire simulation period (Disturbed Scenario)

Undisturbed Scenario: Waste Inventory Case 1







- **RN transport greatly retarded in the far-field interbed by sorption**
- **Non-sorbing or weakly sorbing RNs (I-129, Se-79, Cl-36) with a significant inventory are released from the far-field interbed at noticeable rates**
- **I-129 is the dominant long-term dose contributor**
  - **unconstrained solubility**
  - **Extremely long half-life (~16 M yrs)**
  - **Significant inventory in the waste**

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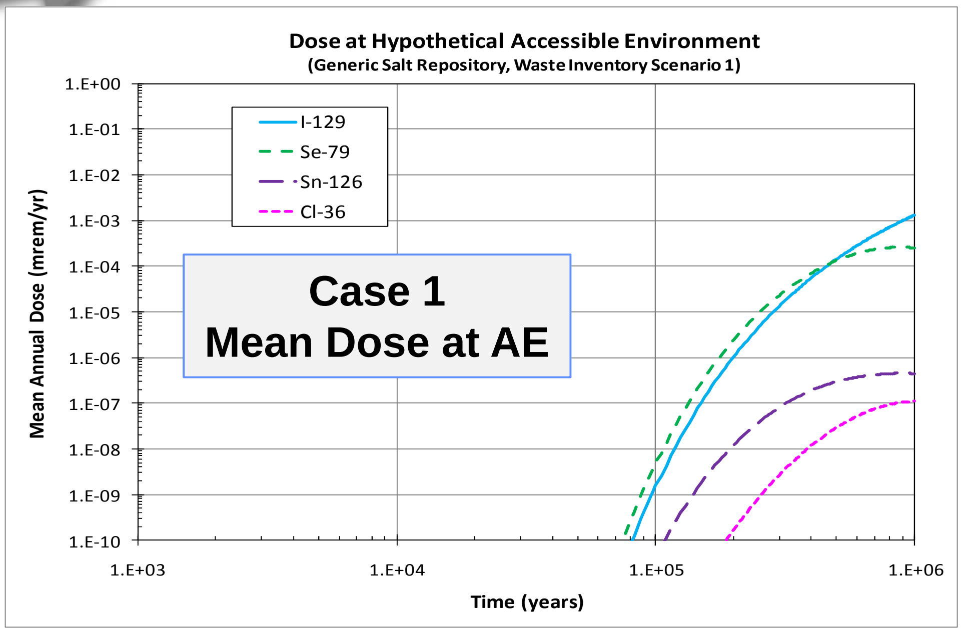
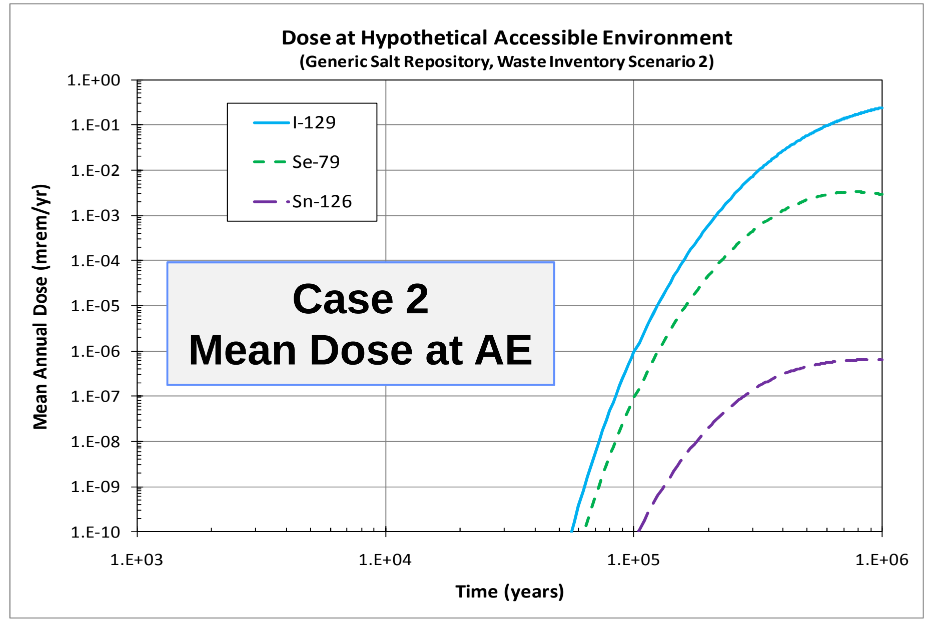
Undisturbed Scenario: Waste Inventory Case 1 vs. Case 2





- **Higher mean peak dose for Waste Inventory Case 2**
  - **Higher fission products inventory on a per-WP basis for Waste Inventory Case 2**
    - **Assumptions on the reprocessing HLW inventory**
  - **Degradation rate of the glass waste form (DOE HLW and reprocessing HLW) 2 to 3 orders of magnitude higher than the UNF degradation rate**
  - **Higher concentrations of soluble RNs (I-129, Se-79) in the near-field water for Waste Inventory Case 2**
    - **A smaller near-field water volume**

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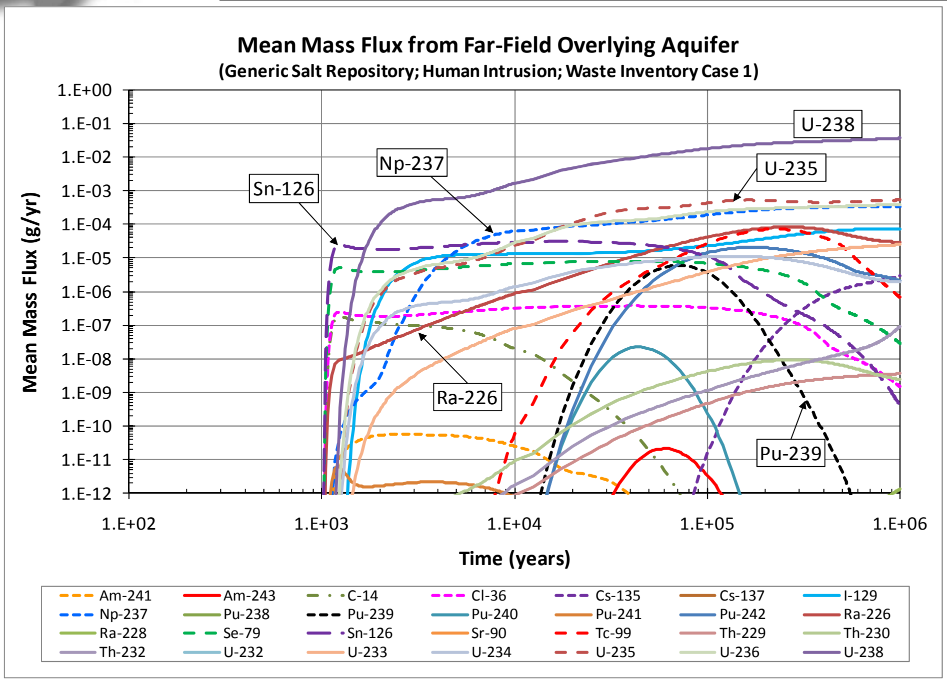
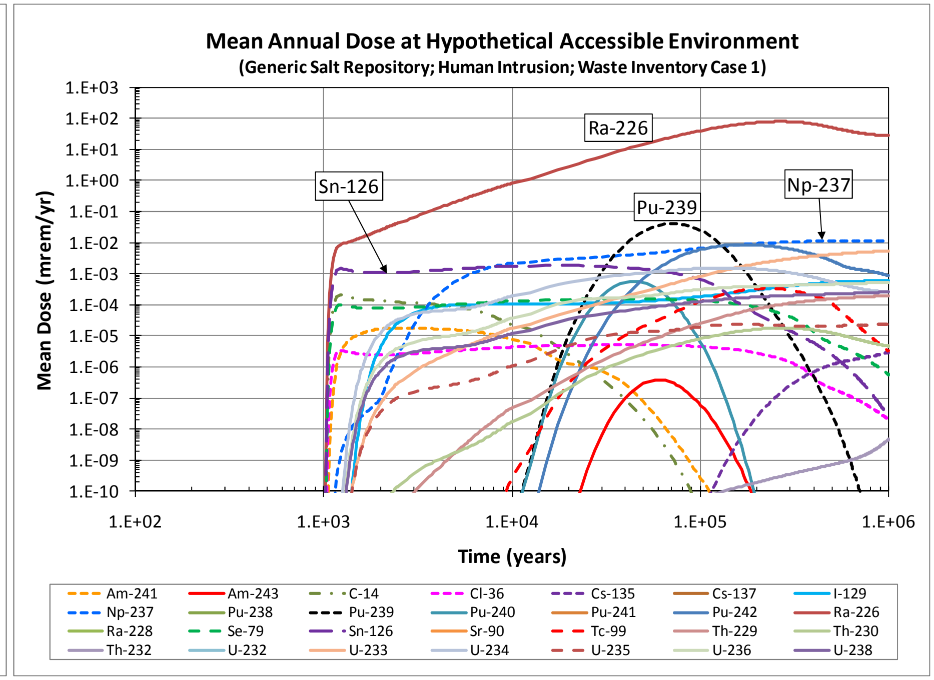
Disturbed Scenario: Waste Inventory Case 1





- **Different mass release rate and dose histories from Undisturbed Scenario**
  - **RNs transported advectively at much higher rates in the overlying aquifer than the interbed**
- **Ra-226 is the dominant dose contributor**
  - **Assume unconstrained solubility and non-sorbing behavior for Ra**
  - **Ra known to readily sorb on geologic materials and not mobile in groundwater**
- **Higher doses for the actinides due to direct release into the overlying aquifer with higher water flow rates**

Summary and Conclusions

- Soluble, non-sorbing fission products (I-129, Se-79) are the major dose contributors
  - Uncertain solubility and sorption behavior in chemically reducing geologic environments
- RN release pathways and scenarios are important to the response of a generic salt repository
  - Improved conceptual models that are more representative of a salt repository
- Need to evaluate impact of the conceptual model simplification and bounding conservative assumptions
  - Brine movement under thermal perturbation
  - WP performance
  - Geologic behaviors of key RNs (I, Se, Ra)

Future Work

- **Develop analysis tools for thermal loading and thermo-hydrologic response in generic salt repository, incorporating associated processes**
  - **Salt creep deformation and consolidation**
  - **Brine movement**
- **Improve near-field chemistry for generic salt repository environment**
  - **High ionic strength, elevated temperature, reducing condition**
  - **Solubility and sorption of RNs in near-field environments**
- **Flow and RN transport in generic interbed**
- **Degradation of WP, candidate waste forms and other EBS components in generic salt repository environment**
  - **Characterization and quantification of gases generated from corrosion in concentrated brine under reducing condition**

Backup Slides

Near-Field and Far-Field Radionuclide Elemental Solubility

Near-field Radionuclide Elemental Solubility

Element	Distribution Type	Solubility (molal)
U	Triangular	4.89E-08 (min); 1.12E-07 (mode); 2.57E-07 (max)
Pu	Triangular	1.40E-06 (min); 4.62E-06 (mode); 1.53E-05 (max)
Am	Triangular	1.85E-07 (min); 5.85E-07 (mode); 1.85E-06 (max)
Np	Triangular	4.79E-10 (min); 1.51E-09 (mode); 4.79E-09 (max)
Th	Triangular	2.00E-03 (min); 4.00E-03 (mode); 7.97E-03 (max)
Tc	Log-Triangular	4.56E-10 (min); 1.33E-08 (mode); 3.91E-07 (max)
Sn	Triangular	9.87E-09 (min); 2.66E-08 (mode); 7.15E-08 (max)
C, Cl, Cs, I, Se, Sr	n/a	Unlimited solubility

Note: Source: Ref. 3.
- Chemically reducing conditions.
- Elements Ac, Cm, Nb, Pa, Pd, Ra, Sb, Zr are known to be solubility-limited, but are implemented as unlimited solubility in the near- and far-field model because their solubility calculations have not been completed.

Far-field Radionuclide Elemental Solubility

Element	Distribution Type	Solubility (molal)
U	Triangular	9.16E-05 (min); 2.64E-04 (mode); 7.62E-04 (max)
Pu	Triangular	7.80E-07 (min); 2.58E-06 (mode); 8.55E-06 (max)
Am	Triangular	3.34E-07 (min); 1.06E-06 (mode); 3.34E-06 (max0
Np	Log-triangular	1.11E-06 (min); 1.11E-05 (mode); 1.11E-04 (max)
Th	Triangular	8.84E-06 (min); 1.76E-05 (mode); 3.52E-05 (max)
Sn	Triangular	1.78E-08 (min); 4.80E-08 (mode); 1.29E-07 (max)
C, Cl, Cs, I, Se, Sr, Tc	n/a	Unlimited solubility

Note: Source: Ref. 3.
- Chemically less reducing conditions than the near-field concentrated brines.
- Elements Ac, Cm, Nb, Pa, Pd, Ra, Sb, Zr are known to be solubility-limited, but are implemented as unlimited solubility in the near- and far-field model because their solubility calculations have not been completed.

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Radionuclide Transport Parameters

Interbed Transport Parameters

Parameter	Distribution Type	Parameter Value
Aquifer thickness	Constant	4 m
Matrix porosity	Uniform	0.07 (min); 0.3 (max)
Bulk density	Constant	2800 kg/m^3
Matrix Tortuosity	Uniform	0.03 (min); 0.5 (max)
Brine flow rate upward through borehole (m^3/yr)	Uniform	0.1 (min); 5.0 (max)
Aquifer water flow rate (m/yr)	Log-uniform	3.15E-03 (min); 3.15E+01 (max)
Longitudinal Dispersivity	Constant	10% of flow conduit length
Kd for Radioelements (ml/g) :		
Uranium	Uniform	0.03 (min); 20 (max)
Plutonium	Log-uniform	20 (min); 1.0E+04 (max)
Neptunium	Log-uniform	1 (min); 200 (max)
Americium	Uniform	20 (min); 400 (max)
Thorium	Log-uniform	7.0E+02 (min); 1.0E+04 (max)
Technetium	Triangular	0 (min); 50 (mode); 100 (max)
Cesium	Triangular	40 (min); 500 (mode); 3000 (max)
Strontium	Triangular	5 (min); 13 (mode); 4.0E+04 (max)
Iodine	Uniform	0.01 (min); 100 (max)
Carbon, chlorine, Selenium & Tin	Constant	0 (no sorption)

Carbonate Aquifer Transport Parameters

Parameter	Distribution Type	Parameter Value
Thickness	Constant	1 m
Porosity	Constant	0.01
Density	Constant	2500 kg/m^3
Brine flow rate below repository (m/yr)	Log-uniform	1.0E-08 (min); 3.0E-02 (max)
Brine flow rate away from repository (m/yr)	Log-uniform	1.0E-08 (min); 2.0E-02 (max)
Longitudinal Dispersivity	Constant	10% of flow conduit length
Kd for Radioelements (ml/g) :		
Uranium	Uniform	0.2 (min); 1 (max)
Plutonium	Uniform	70 (min); 100 (max)
Neptunium	Uniform	1 (min); 10 (max)
Americium	Uniform	25 (min); 100 (max)
Thorium	Uniform	100 (min); 1000 (max)
Technetium	Uniform	0 (min); 2 (max)
Cesium	Uniform	1 (min); 20 (max)
Strontium	Uniform	1 (min); 80 (max)
Carbon, chlorine, Selenium & Tin	Constant	0 (no sorption)

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Undisturbed Scenario: Waste Inventory Case 2