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A Preliminary Performance Assessment for Salt Disposal of High-Level Nuclear Waste

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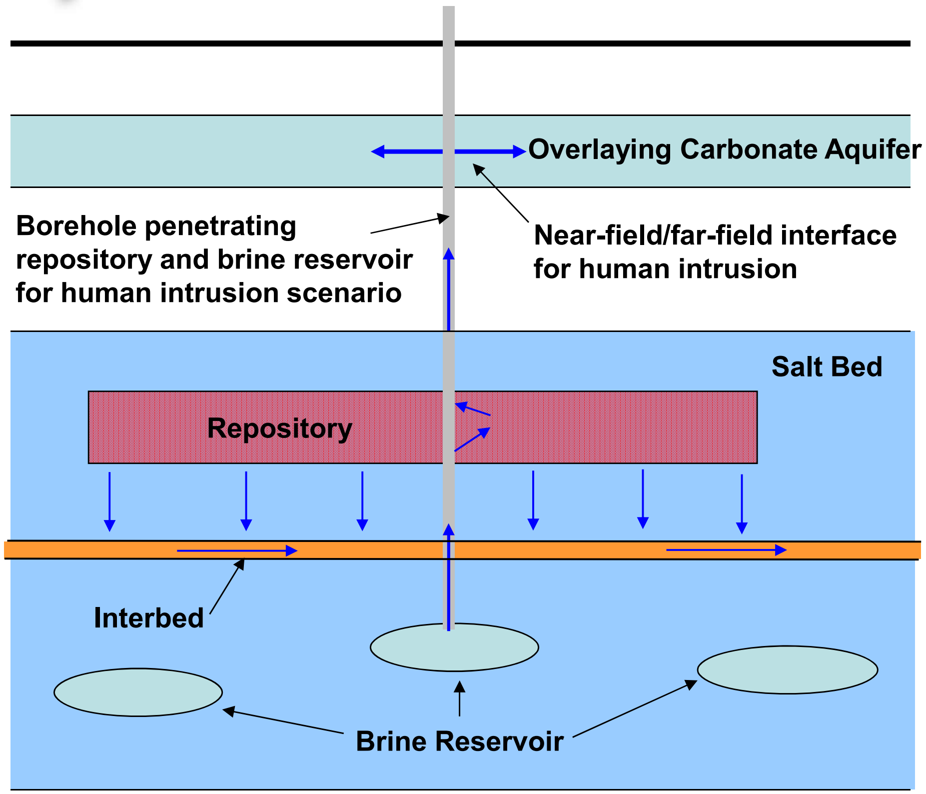
Outline

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

Introduction

- Salt repository is one of four generic disposal system (GDS) 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 GDS study is to support the development of a long-term strategy for geologic disposal of high-level nuclear 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

Conceptual Model



- Assume saturated, reducing condition
  - Repository in a bedded salt formation below a carbonate aquifer
- Isothermal condition at ambient temperature
- Reference (or Undisturbed) Scenario
  - RNs released into and transported in an interbed (1 m thick, relatively more permeable anhydrite layer) 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)

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Waste Inventories and Scenarios
(continued)

- **Assume a square repository footprint**
  - Spacing between emplacement tunnels: 25 m
  - Spacing between WPs: 6 m
- **Waste inventory case for Reference Scenario**
  - UNF plus DOE HLW
    - A total of 37,157 WPs
    - A square repository footprint with a side of 3,270 m
- **Waste inventory case for Disturbed Scenario**
  - Assume only UNF WPs affected by human intrusion
  - No additional WP failures by nominal degradation process

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)**
- **RN sorption in the near-field and far-field transport**
  - **Linear equilibrium sorption (K_d) model for interbed and overlying carbonate aquifer**

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Radionuclide Mobilization and Transport
(continued)

- Brine pore flow velocity in the repository and interbed (Reference Scenario)
  - Time-dependent flow rates (<10^{-16} m/yr to 10^{-6} m/yr) from BRAGFLO analysis
- Pore flow velocity in overlying carbonate aquifer (Disturbed Scenario)
  - Log-uniform (3.1×10^{-3} m/yr, 31 m/yr) (consistent with WIPP modeling)
- Performance measure matrix
  - Mean mass flux from major system components (e.g., near-field and far-field boundaries)
  - Mean annual 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
- The salt GDS model implemented in the Goldsim framework
  - Probabilistic performance analysis with 100 realizations for a time period of 1 M years

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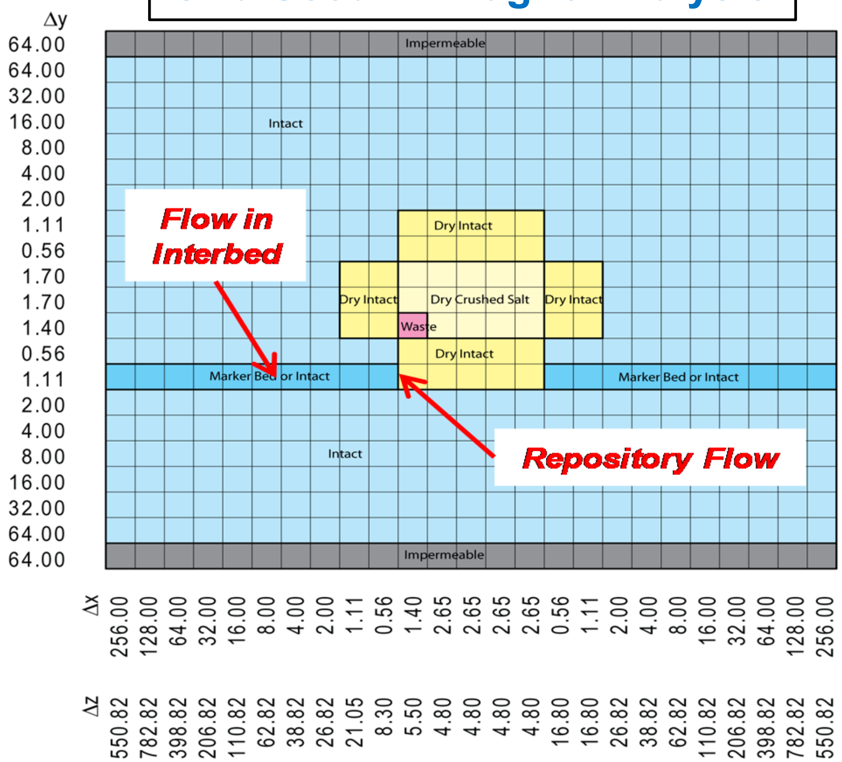
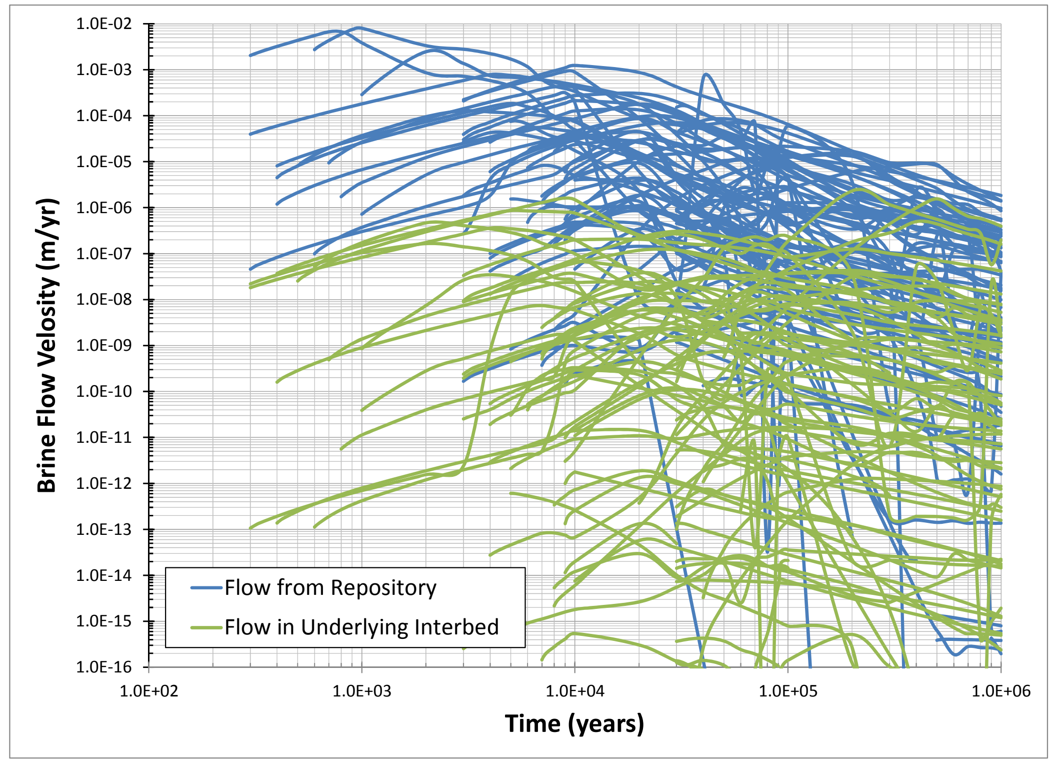
Abstraction for BRAGFLO Analysis Results for Brine Flow

Grid Used in Bragflo Analysis





- **Assume initial dry-out zones around waste disposal area and isothermal condition at ambient temperature**
- **100 time-dependent brine flow rate histories at two locations**
  - **Edge of the initial dry-out zone below waste disposal area**
  - **Underlying interbed (used also for brine flow in the far-field interbed)**

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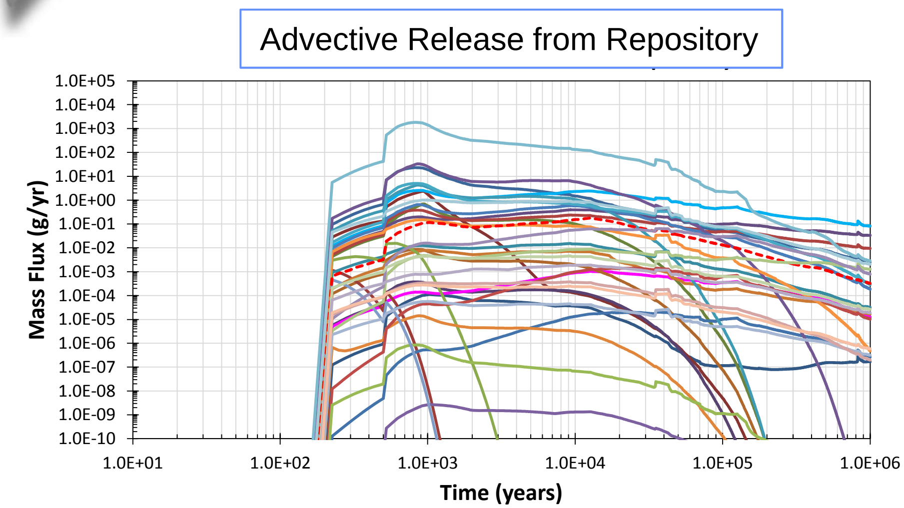
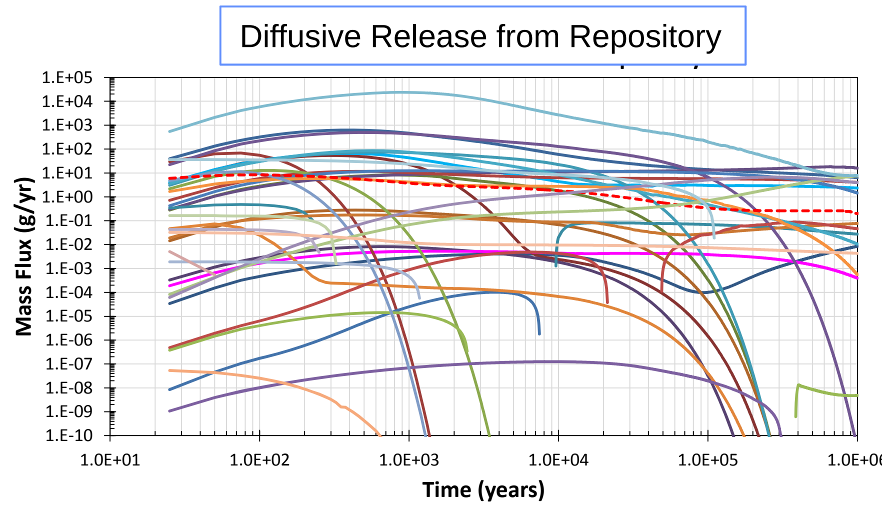
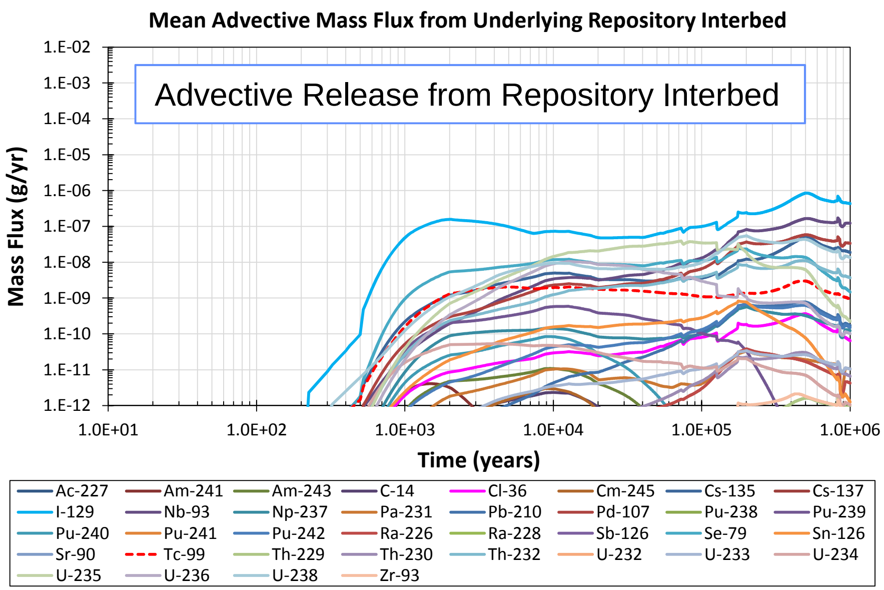
Major Conservative Bounding Assumptions

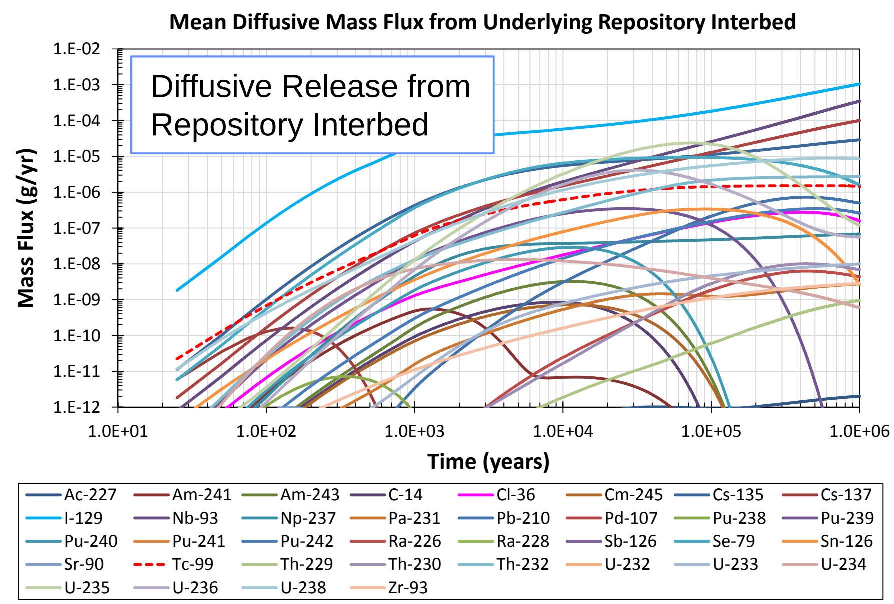
- No containment barrier performance of waste package
- Not consider RN release delays during initial dry-out period around the waste disposal area due to waste decay heat
  - The extent and duration of dry-out depending on many factors such as repository thermal loading, WP heat output characteristics, repository thermal-hydrologic response, etc.
- No RN sorption on degradation products of EBS components and geologic materials in the mixing cell representing waste disposal area
- Use of brine pore velocity in the near-field interbed for the far-field interbed for the entire simulation period (Reference Scenario)
- Continuous steady-state upward brine flows through the borehole for the entire simulation period (Human Intrusion Case)

Preliminary Results for Nominal Scenario









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Preliminary Results for Nominal Scenario
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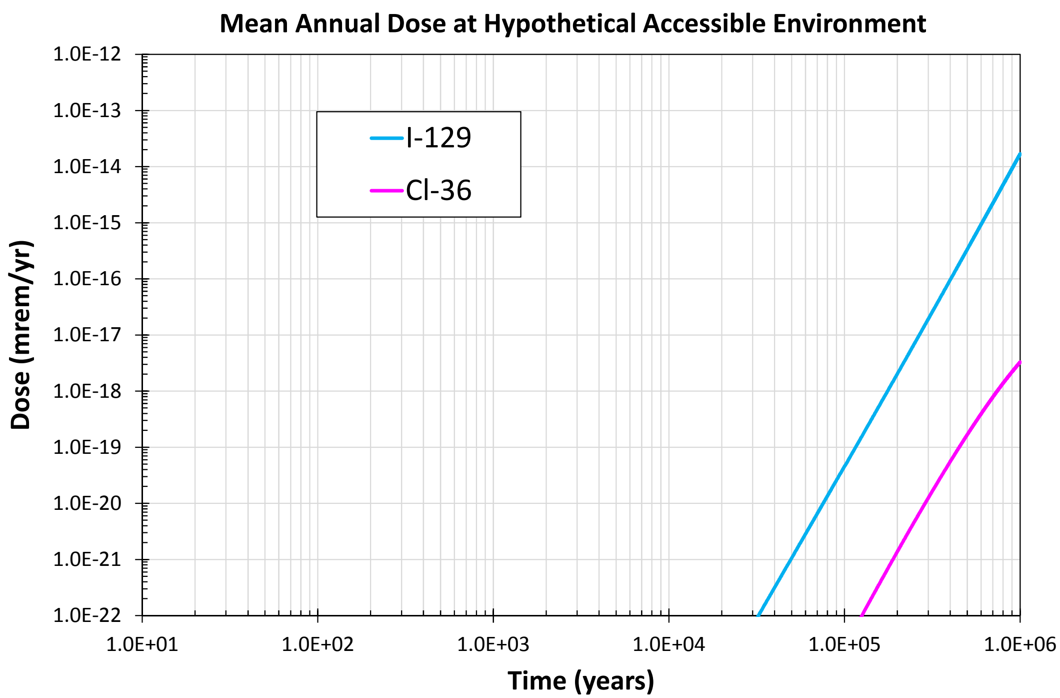

- **Slow, diffusion-dominated transport in interbeds**
  - **Very low brine pore flow velocities in interbeds**
- **RN transport further retarded in the interbed by sorption**
- **Non-sorbing or weakly sorbing RNs (I-129, Cl-36) with a significant inventory are released from the far-field interbed**
- **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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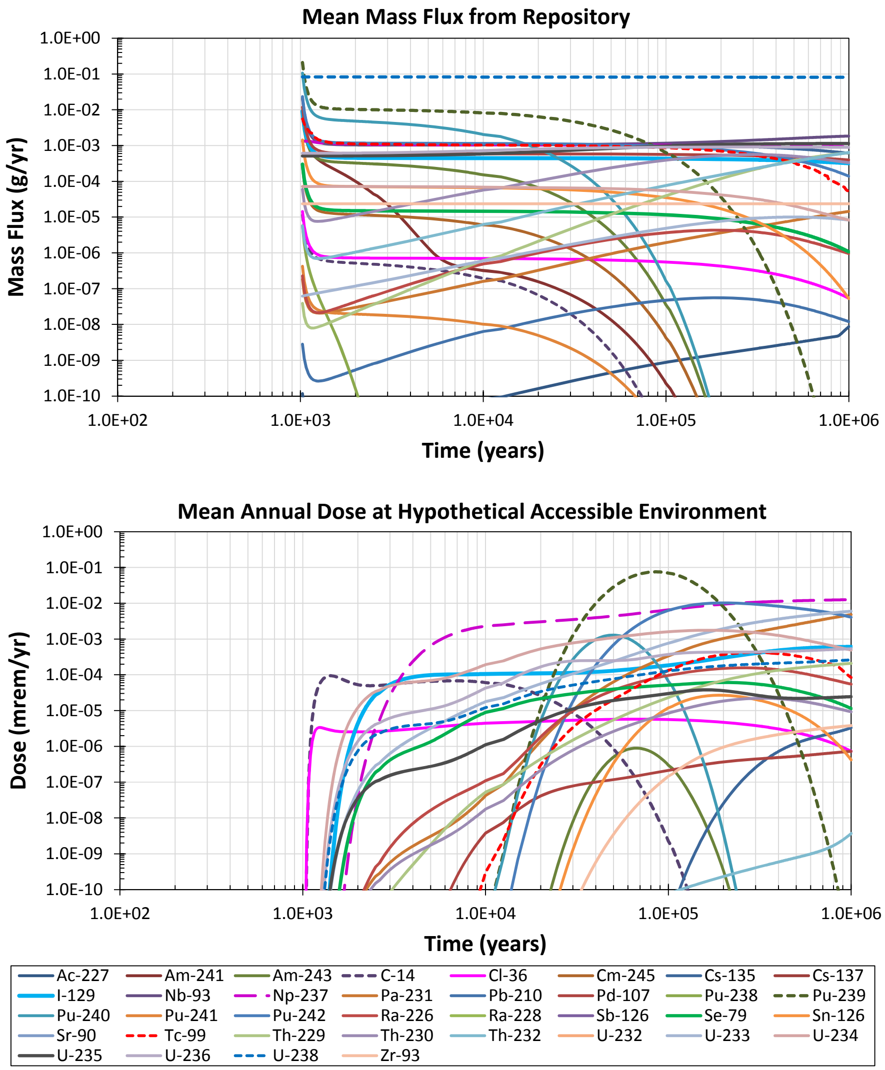
Preliminary Results for Disturbed Scenario (Human Intrusion Case)



- **Higher dose estimates than for nominal scenario although available inventory is much smaller**
  - RNs transported at much higher rates in the overlying aquifer than in the interbed
- **Actinides contribute due to direct release into the overlying aquifer with higher water flow rates and higher solubility limits**
- **Np-237, Pu-239, and Pu-242 are the dominant dose contributors**
  - I-129 is no longer a dominant dose contributor because of its limited inventory
  - Only one to five WPs fail

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Summary and Conclusions

- Developed a performance assessment model for a generic salt repository
  - Incorporated, where applicable, representative geologic settings and features adopted from literature data for existing salt repository sites
- RN release pathways and scenarios are important to the response of a generic salt repository
  - Improved conceptual models that are more representative of a generic salt repository
- Soluble, non-sorbing fission products (I-129, Cl-36) are the major dose contributors for Nominal Scenario
  - Uncertain solubility and sorption behavior in chemically reducing geologic environments
- Actinides are dominant dose contributors for Human Intrusion Case
  - Direct releases of the RNs into the overlying aquifer

Summary and Conclusions
(continued)

- 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, Cl)

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 geochemistry for generic salt repository environment**
  - High ionic strength, elevated temperature, reducing condition
  - Solubility and sorption of RNs in near-field environments
- **Degradation of WP, 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
- **Brine flow and RN transport in the far-field of generic salt repository**
  - Transport in generic interbed