

# Preliminary Feasibility Analysis for Direct Disposal of Electrorefiner (ER) Salt Waste in Salt Repository

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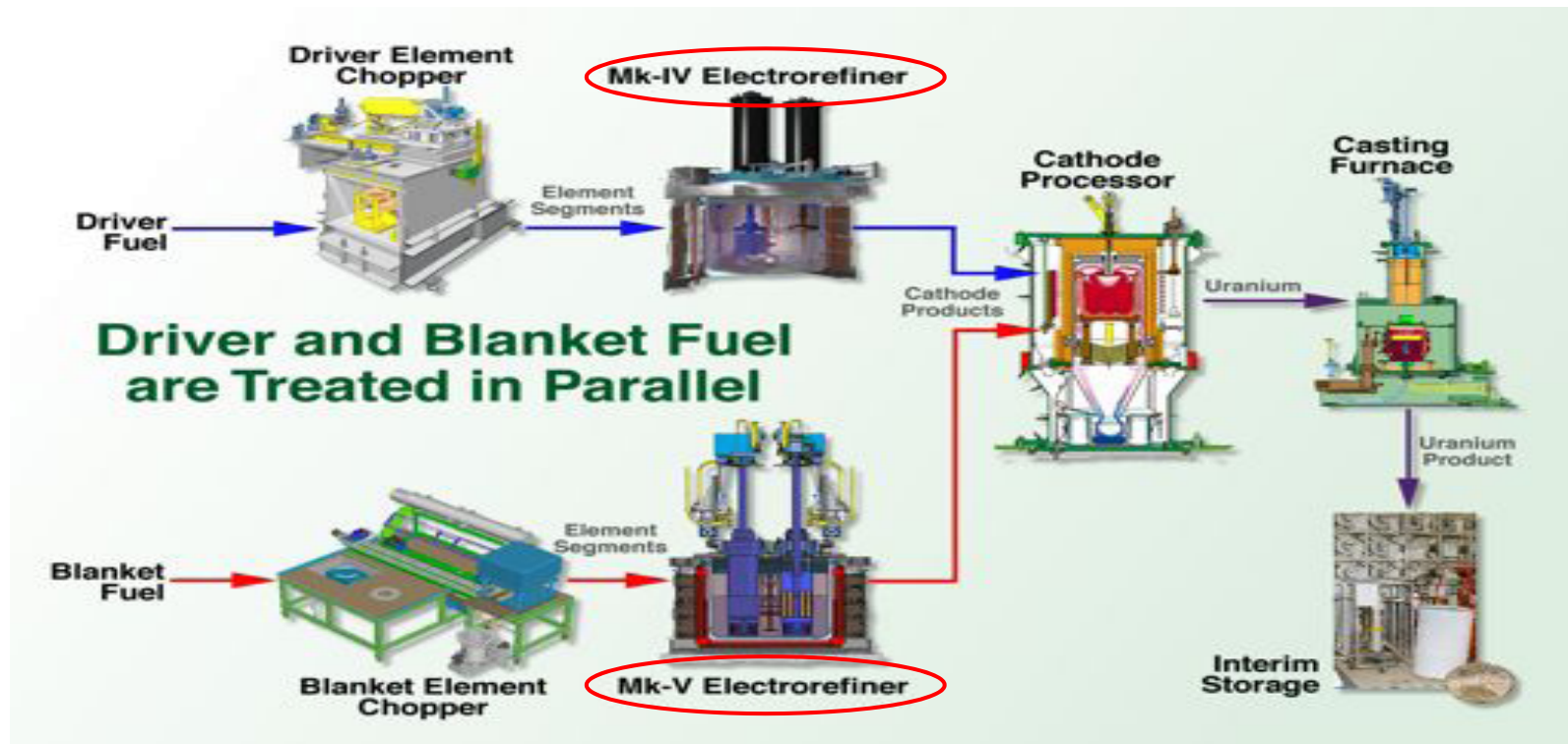


# Outline

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- **Introduction**
- **Electrorefiner (ER) salt waste**
  - Waste inventories
  - Waste heat output
- **Repository RN release scenario and conceptual model**
- **Source term model**
  - WP corrosion degradation
  - Salt waste dissolution
- **Natural barrier system model**
- **Biosphere model**
- **Model implementation**
- **Preliminary analysis results**
- **Summary and conclusions**
- **Future work**

# Electrorefining Process



- Electrorefining process developed for recycle of metallic fast reactor spent fuel (e.g., EBR-II)
  - Oxide reduction required for oxide spent fuel
- Mark-IV electrorefiner (ER) designed for treating driver fuel (low Pu and highly enriched U)
- Mark-V ER designed for treating blanket fuel (depleted U with ~1% Pu for breeding)

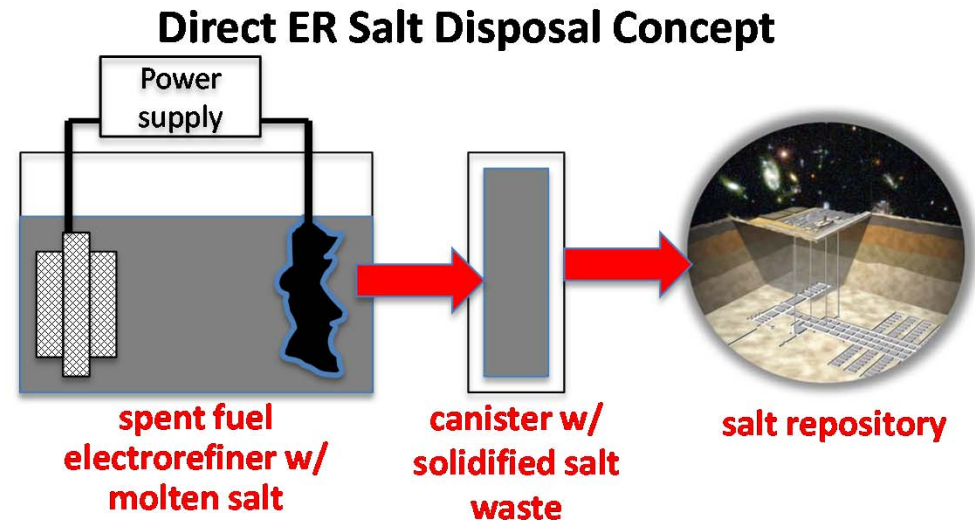
# Issues Related to ER Salt Waste Disposal

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- ER salt waste consists of 70 to 80 wt. % of LiCl-KCl-NaCl (primarily LiCl-KCl)
- ER salt waste phases, except LiCl, could be stable thermodynamically in salt formation (dominantly halite NaCl)
- Without stabilization in waste forms or additional treatment, the salt dissolves rapidly in water or brine.
- Not known how this rapid dissolution would impact repository performance
- Waste forms provide near term resistance to dissolution but are expensive to produce

# Objectives

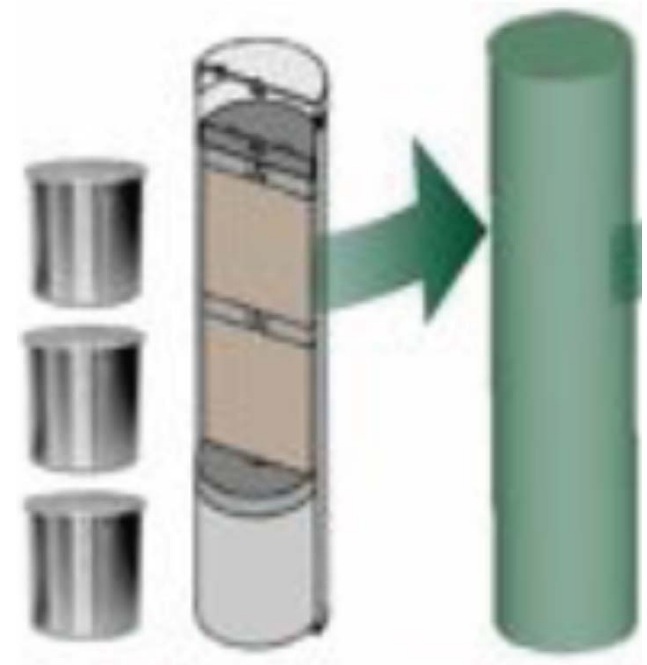
- Conduct a series of performance assessment calculations to assess technical feasibility of direct disposal of electrorefiner (ER) salt in a salt-based repository
- Current default technology for disposing of ER salt is to immobilize it in a glass bonded sodalite (ceramic) waste form (7.5 wt% salt in the waste form)
- Benefits of direct salt disposal:
  - Reduced waste volume
  - Reduced processing cost
  - Reduced processing time



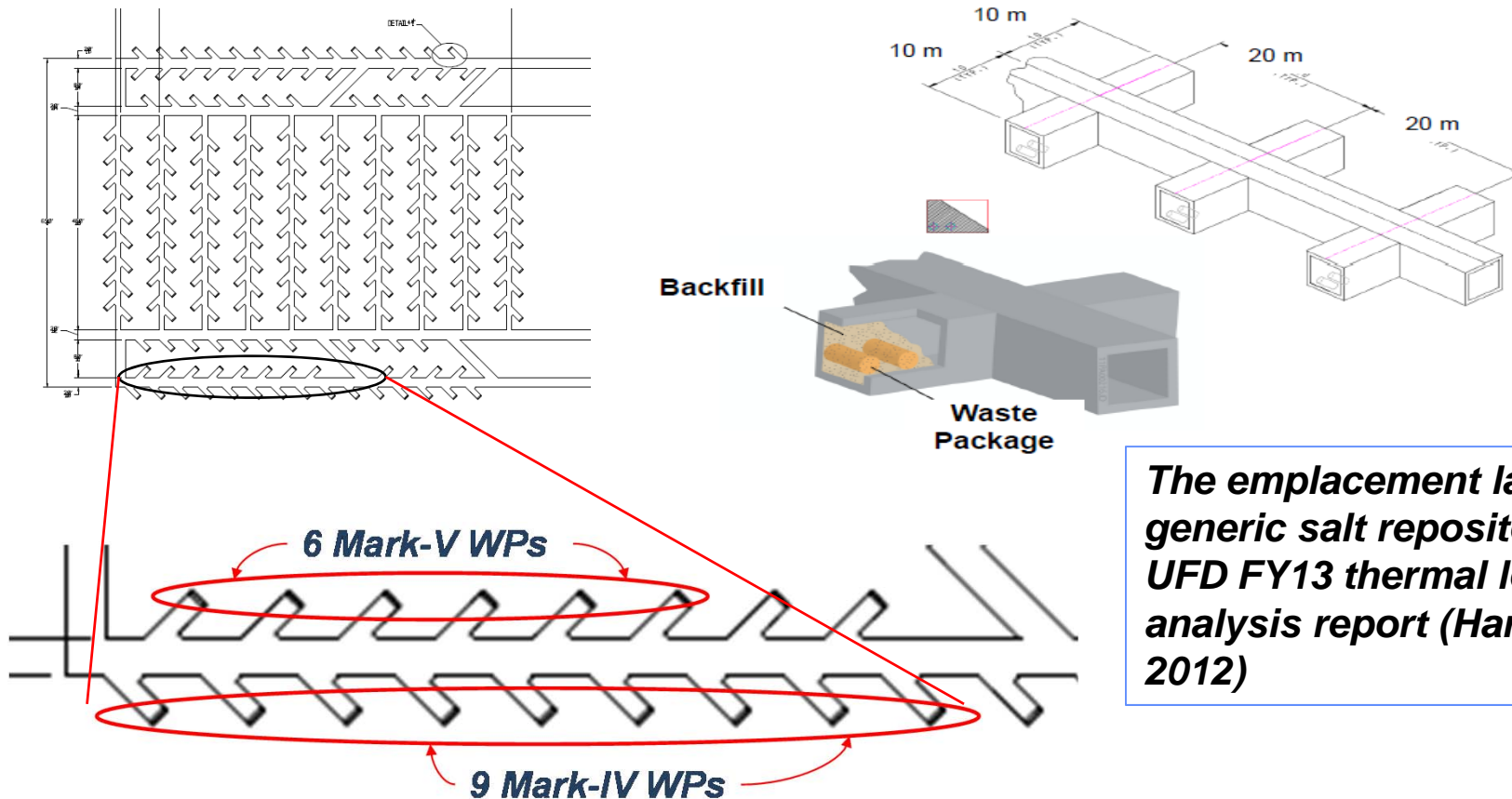
# ER Salt WP Configuration

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- Contaminated molten ER salt poured directly into and solidified in small S.S. containers
  - ~40 kg salt per container
- Three ER salt waste containers stacked up in a thin-walled S.S. disposal canister
  - ~120 kg salt per disposal canister
- Disposal canister placed in carbon steel overpack
- Each WP contains 120 kg (0.12 MT) salt
  - 42 cm OD; 170 cm length
- Projected total inventory of ER salt
  - 1,017 kg of Mark-IV ER salt
  - 700 kg Mark-V ER salt
  - 9 Mark-IV salt WPs; 6 Mark-V salt WPs



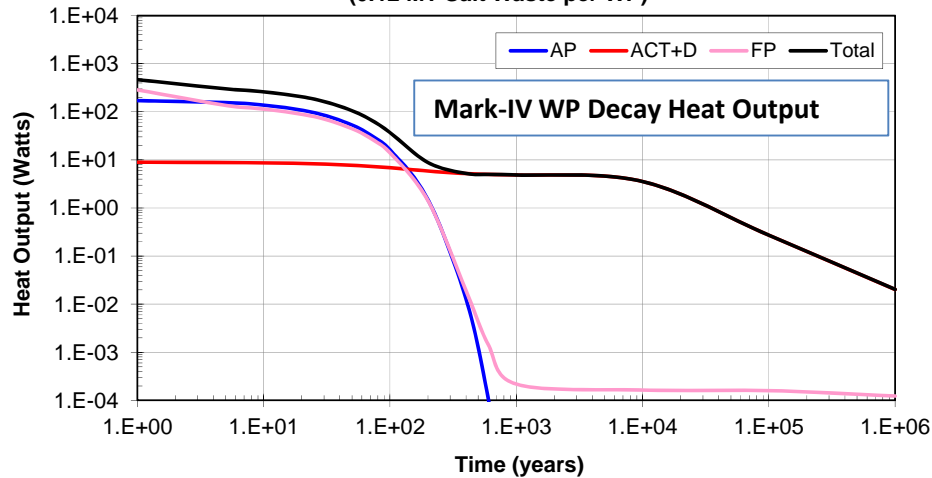
# ER Salt WP Emplacement



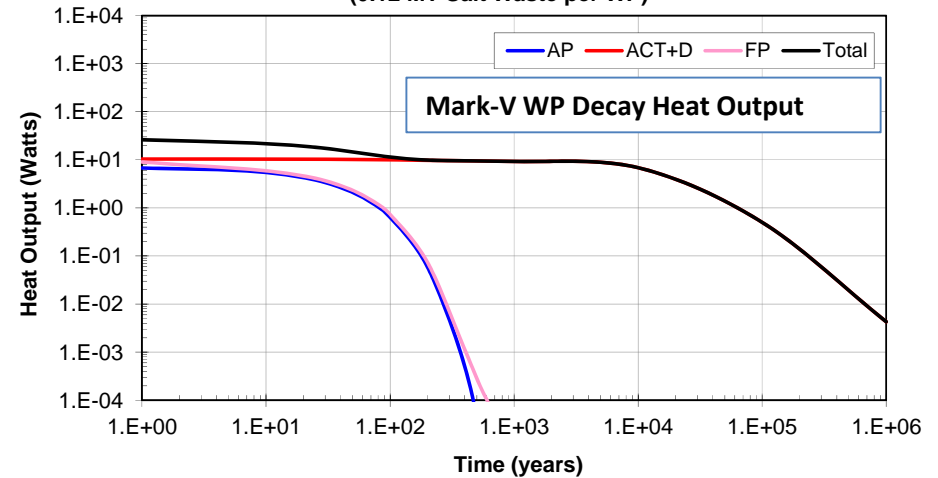
- Assume WPs are placed on the edge of repository footprint and near a repository access shaft
- A single WP is emplaced in an alcove and backfilled with crushed salt
- Assume 20-m WP-to-WP spacing and 20-m emplacement alcove spacing

# ER Salt WP Heat Output and Temperature

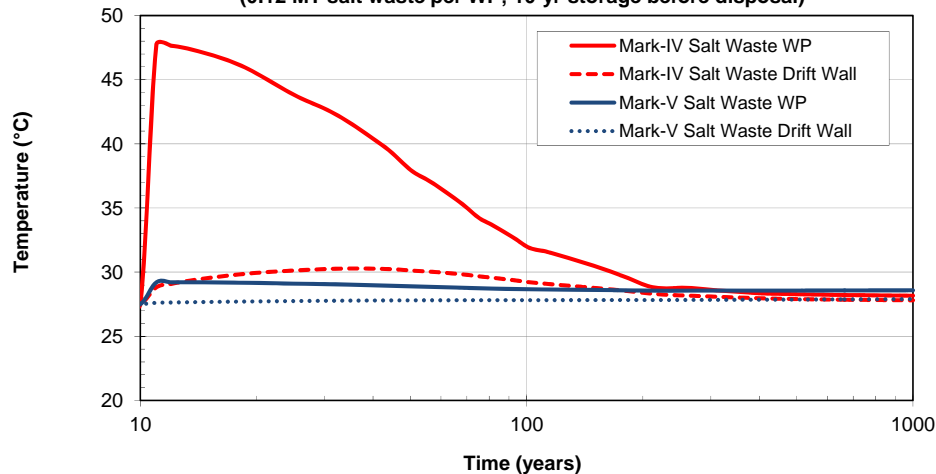
Mark-IV ER Salt Waste Decay Heat Output per WP (Watts)  
(0.12 MT Salt Waste per WP)



Mark-V ER Salt Waste Decay Heat Output per WP (Watts)  
(0.12 MT Salt Waste per WP)



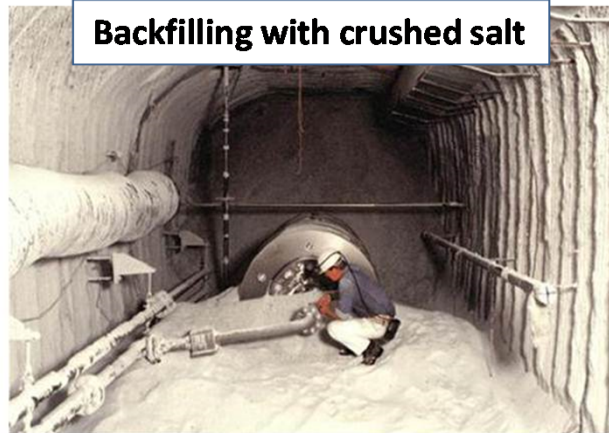
WP and Drift Wall Temperature for ER Salt Waste Disposal  
(0.12 MT salt waste per WP; 10-yr storage before disposal)



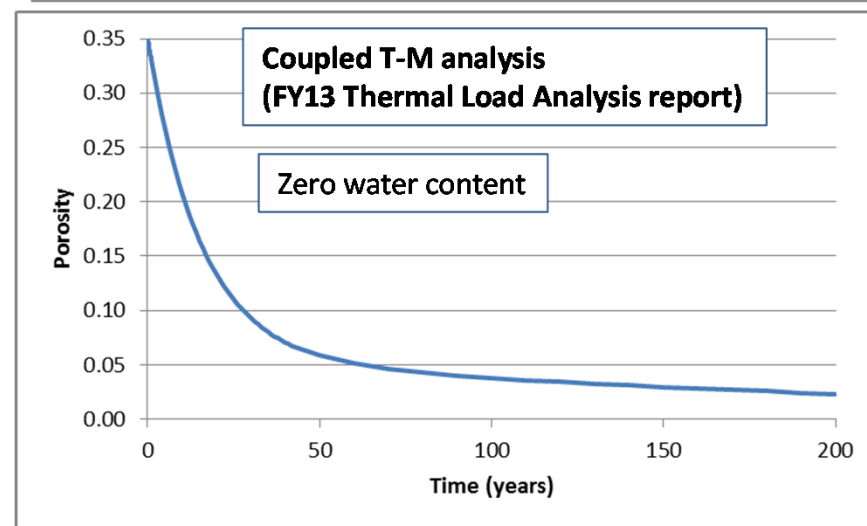
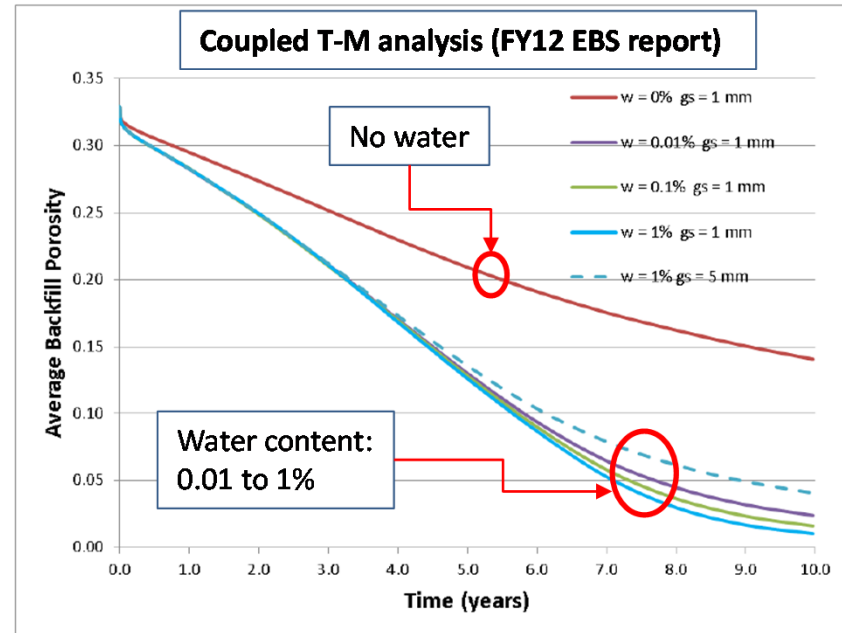
- Assume 10-yr storage prior to disposal
- Moderate peak WP temperature (~50°C) for Mark-IV WP
  - Low WP heat output due to small salt waste loading (0.12 MT/WP)
  - WP temperature cools to the ambient temperature after ~200 yrs

# Salt Creep Deformation and Reconsolidation

**Thermal Simulation of Drift Emplacement (TSDE)  
In-situ Test**  
(Asse Mine; 800-m level; 1990 to 2000)

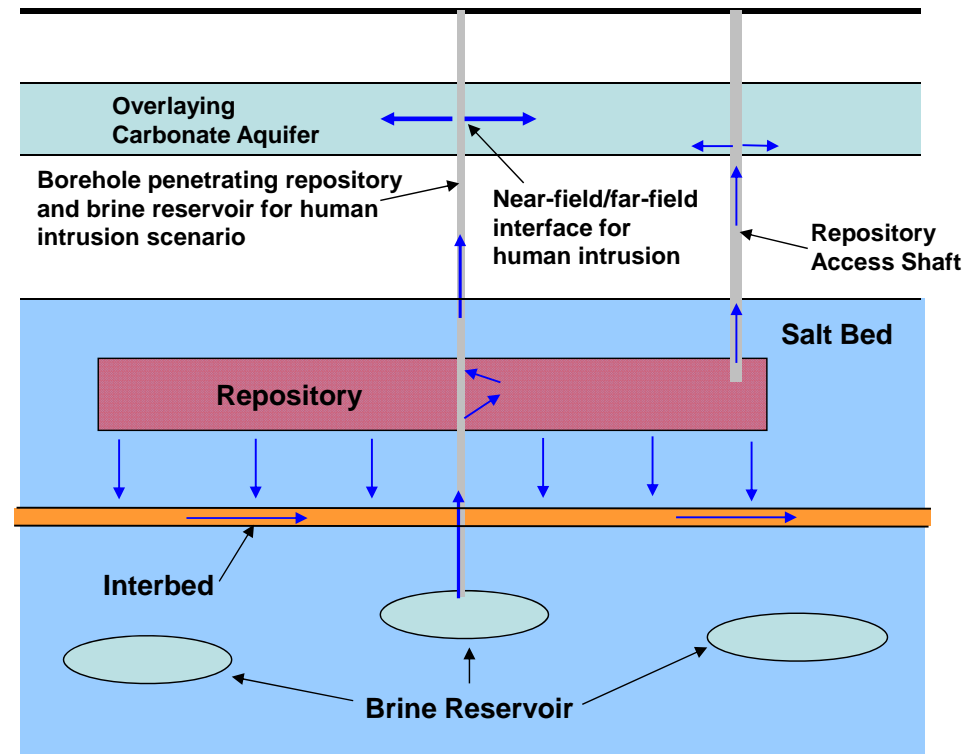


~10 years

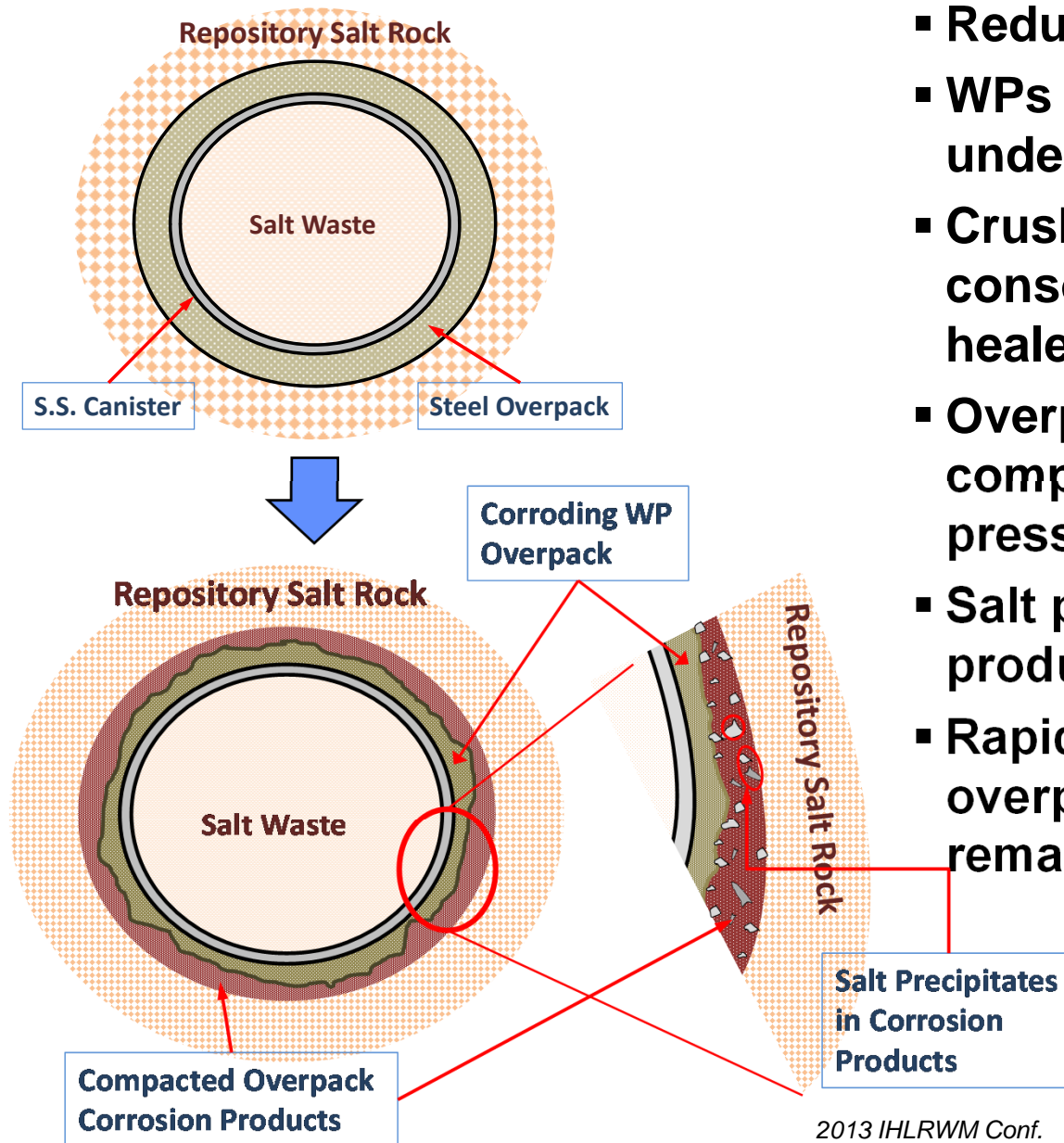


# Repository RN Release Scenario

- Assume saturated, chemically reducing, anoxic condition in repository
  - Repository in a bedded salt formation below a carbonate aquifer
- RNs released to
  - Repository access shaft
  - Underlying interbed
- RNs released to overlying aquifer from the top of access shaft
  - transported advectively to the biosphere located at the site boundary (5 km down-gradient from the repository footprint)
- RNs released to underlying interbed remain in the interbed
  - No credible hydrogeological features to connect the interbed to biosphere



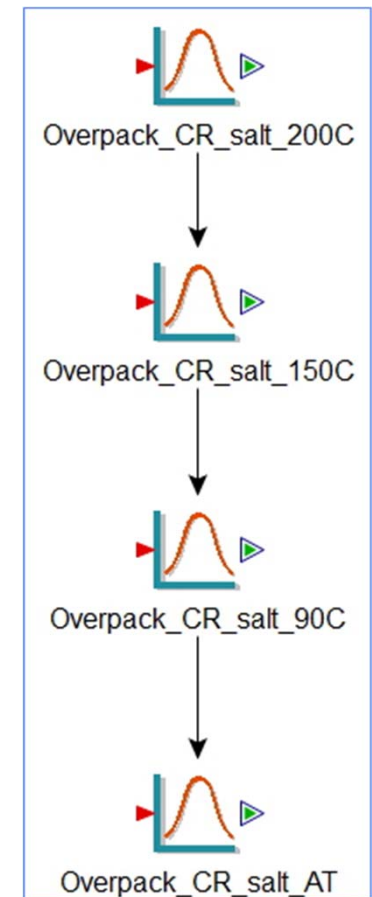
# WP Corrosion Environment



- Reducing anoxic condition
- WPs are encapsulated by salt rock undergoing creep deformation
- Crushed salt backfill fully consolidated and EDZ completely healed to intact salt
- Overpack corrosion products compacted under lithostatic pressure
- Salt precipitates in corrosion product pores
- Rapid buildup of H<sub>2</sub> gas overpressure in confined remaining pore space
- Mean porosity of 0.05 (min 0.01; max 0.1) used for corrosion products in PA

# Waste Package Degradation Model

- WP corrosion performance by carbon steel overpack only
- Overpack degradation by general corrosion only
  - No localized corrosion attack
- Overpack corrosion rate at 90, 150 and 200°C
  - 6-mo exposure of coupons in contact with salt particles (Westerman et al 1986, PNL-SRP-6221)
  - Combined data from tests with NaCl-saturated brine and MgCl<sub>2</sub>-rich brine
- Overpack corrosion rate at 30°C
  - 24-mo exposure (Telander and Westerman 1992)
- The overpack corrosion rates at different temperatures correlated positively
- WP fails when the overpack corrodes to a threshold remaining thickness of 3 cm



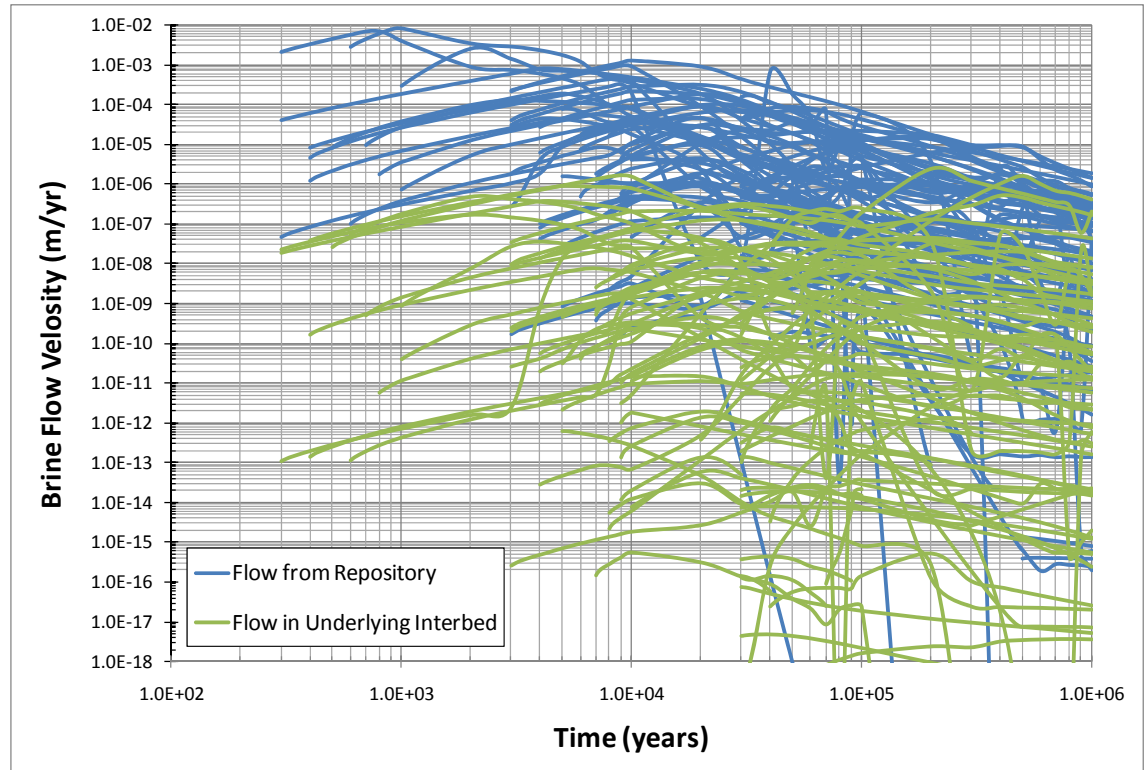
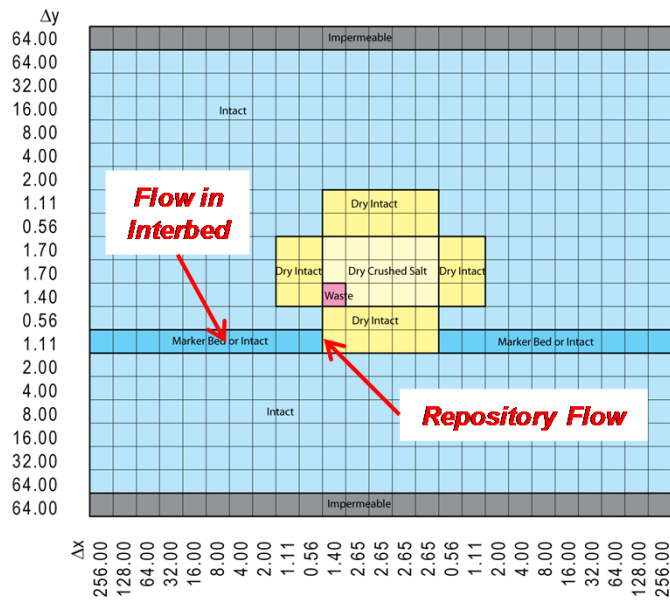
# Salt Waste Dissolution and RN Releases

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- Salt waste dissolution and RN release rate is congruent to LiCl dissolution
  - Conservative as RNs embedded in other salt phases (NaCl, KCl, etc.) may not be readily available for dissolution and releases
- RN releases from salt waste is fast
- Most RNs are subject to their solubility constraints in chemically reducing conditions (except I, C, Cs, Sr, and Ra)

# Abstraction for BRAGFLO Analysis for “Contaminated” Brine Flows in Repository

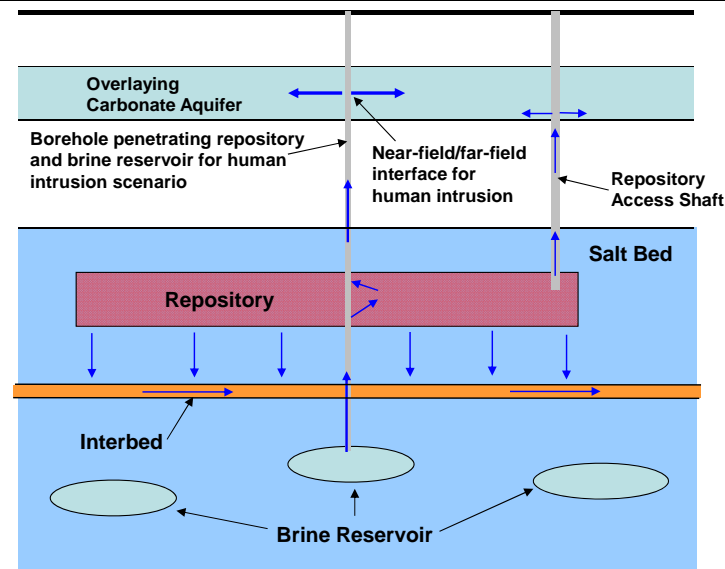
**Grid Used in Bragflo Analysis**



- Isothermal condition at the ambient temperature
- Include effect of H<sub>2</sub> gas pressure build-up from overpack corrosion
- 100 time-dependent flow rate histories at two locations
  - Edge of the initial dry-out zone below waste disposal area
  - Underlying interbed (used also for flow in the far-field interbed)
- Brine flows delayed until WP fails in PA calculations

# Key Generic Natural Barrier System Parameters

Adopted from the reference case parameters recommended in FY12 Salt R&D TSPA report



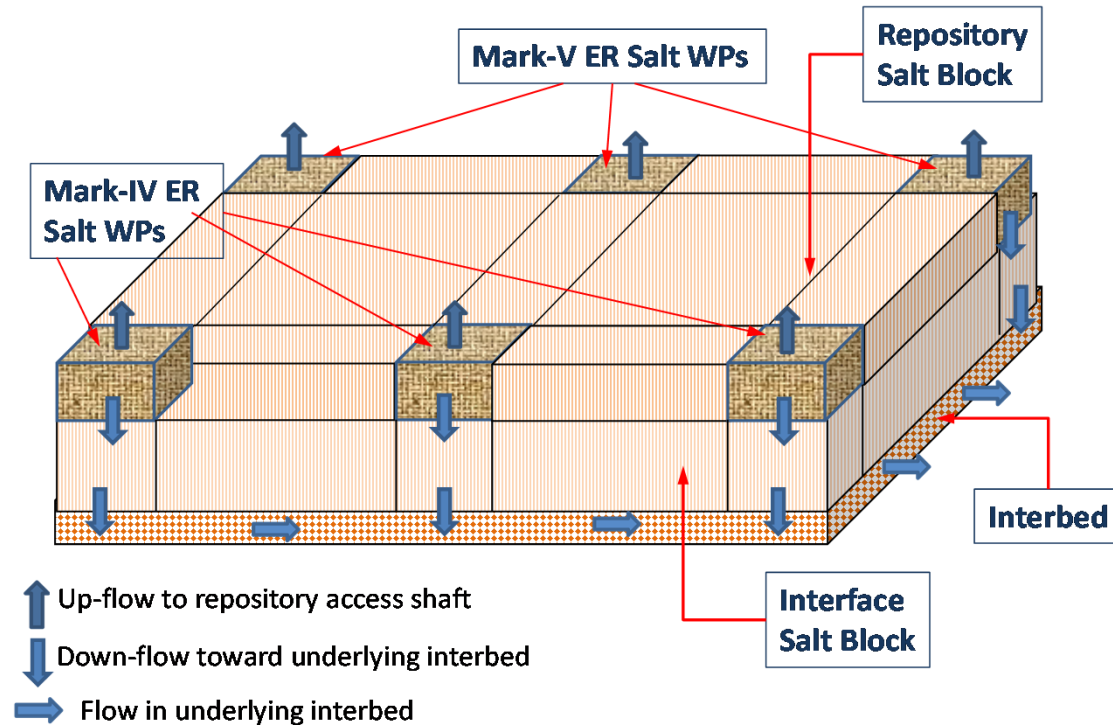
- Interbed thickness: 0.15 – 1.2 m
- Formation thickness between repository floor and interbed: 12 – 15 m
- Formation thickness between repository and aquifer: 152 – 457 m
- Thickness of overlying aquifer: 3 – 23 m
- Diameter of repository access shaft: 5 m
- Length of repository access shaft: 152 – 457 m
- Distance between repository edge and site boundary: 5 km

# Biosphere Model

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- **Assume a “hypothetical” biosphere located at the site boundary**
  - 5 km down-gradient from the edge of repository footprint
- **Development of generic biosphere model is very challenging**
  - Highly uncertain due to potential widely varying biosphere parameters
    - Community life style and size
      - Rural, semi-rural, semi-urban, agricultural, etc.
    - Amount of aquifer groundwater usage
      - Number of wells, pumping rate, etc.
- **The current PA model uses IAEA BIOMASS Example Reference Biosphere 1A (ERB1A) dose model**
  - Based on drinking water consumption
  - Use the dose conversion factor of the model
  - Individual water consumption rate of 1.2 m<sup>3</sup>/yr
  - Use the model-calculated RN concentrations in the far-field aquifer at the site boundary

# Model Implementation



- Implemented in the Goldsim framework
  - Probabilistic performance analysis with 100 realizations for 1 M years
- Model individual WPs
- Diffusive transport links for all 6 sides of each cell

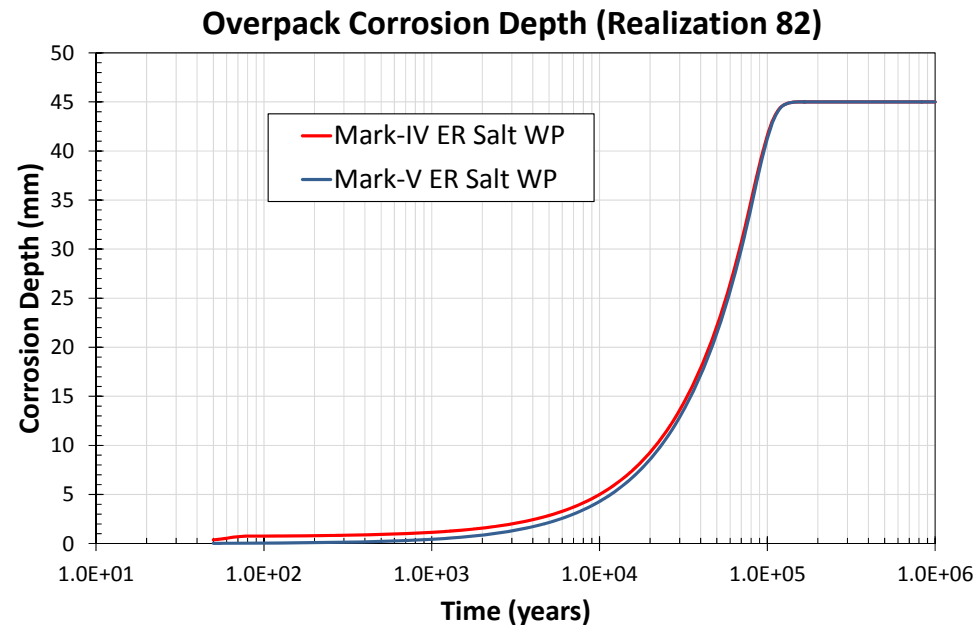
- Pseudo-3D finite difference scheme for RN transport towards underlying interbed
- 1D finite difference scheme for shaft transport
- Width of underlying interbed limited to 40 m (twice the alcove spacing)
  - Limit RN plume spread

# Radionuclide Mobilization and Transport

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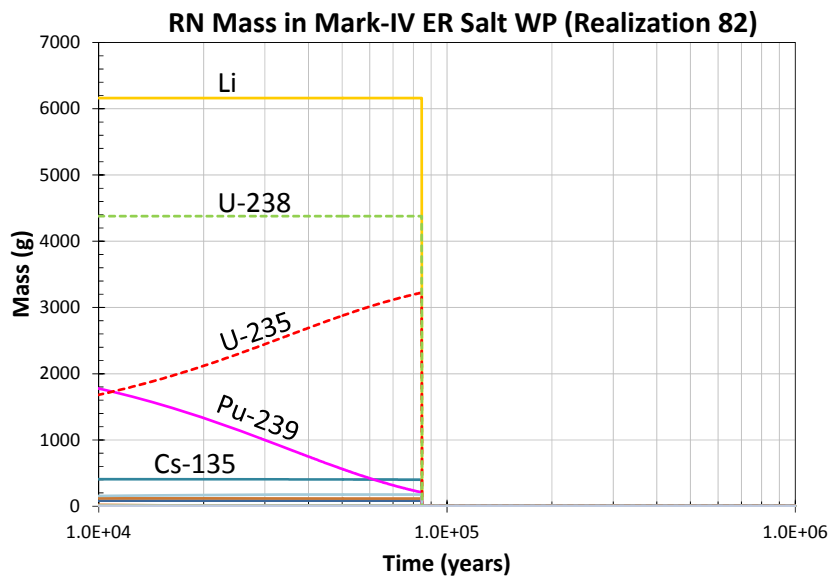
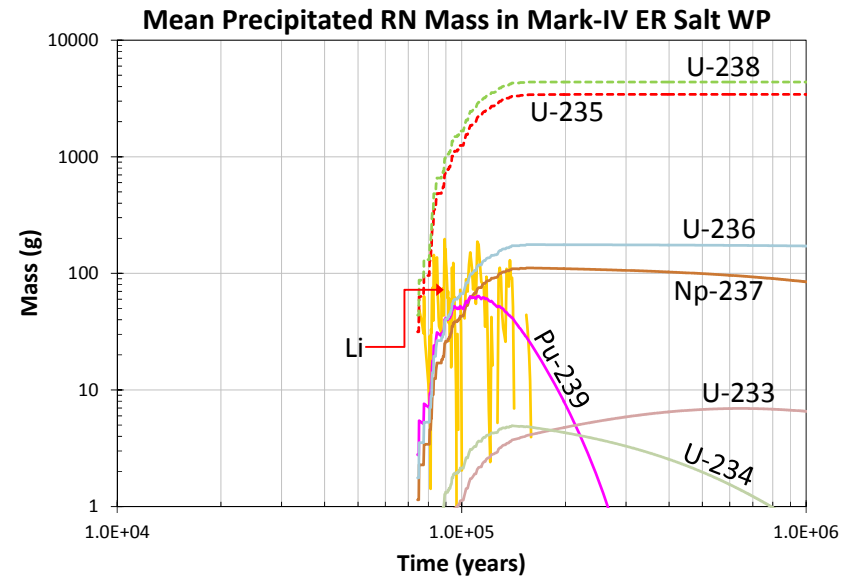
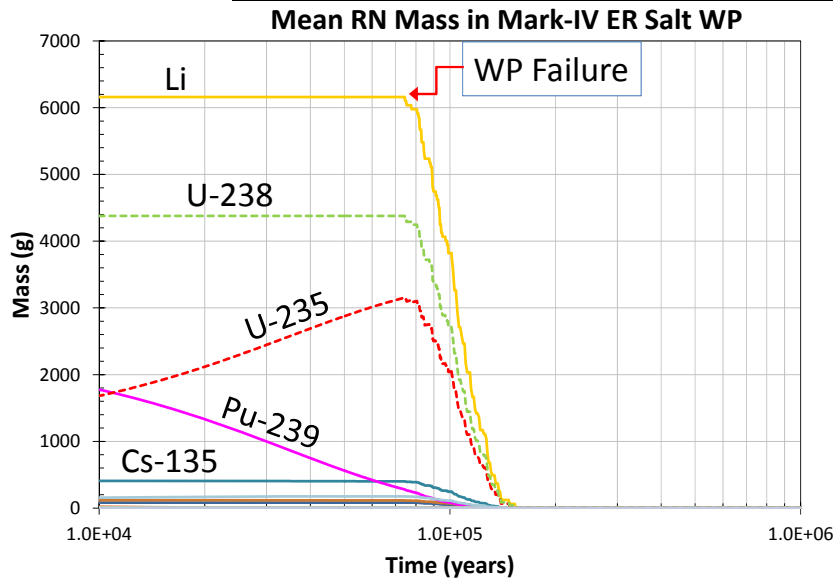
- **Radio-element solubility for two redox conditions**
  - Near-field brines (reducing condition)
  - Far-field brines (less reducing or slightly oxidizing condition)
- **RN sorption in the near-field and far-field transport**
  - Linear equilibrium sorption ( $K_d$ ) model for interbed, access shaft and overlying carbonate aquifer
- **Not consider RN sorption on corrosion products and geologic materials in emplacement alcoves**
- **Brine pore flow velocity in the waste emplacement area, access shaft, and underlying 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**
  - Log-uniform ( $3.1 \times 10^{-3}$  m/yr, 31 m/yr) (consistent with WIPP modeling)

# Waste Package Failure Model Result



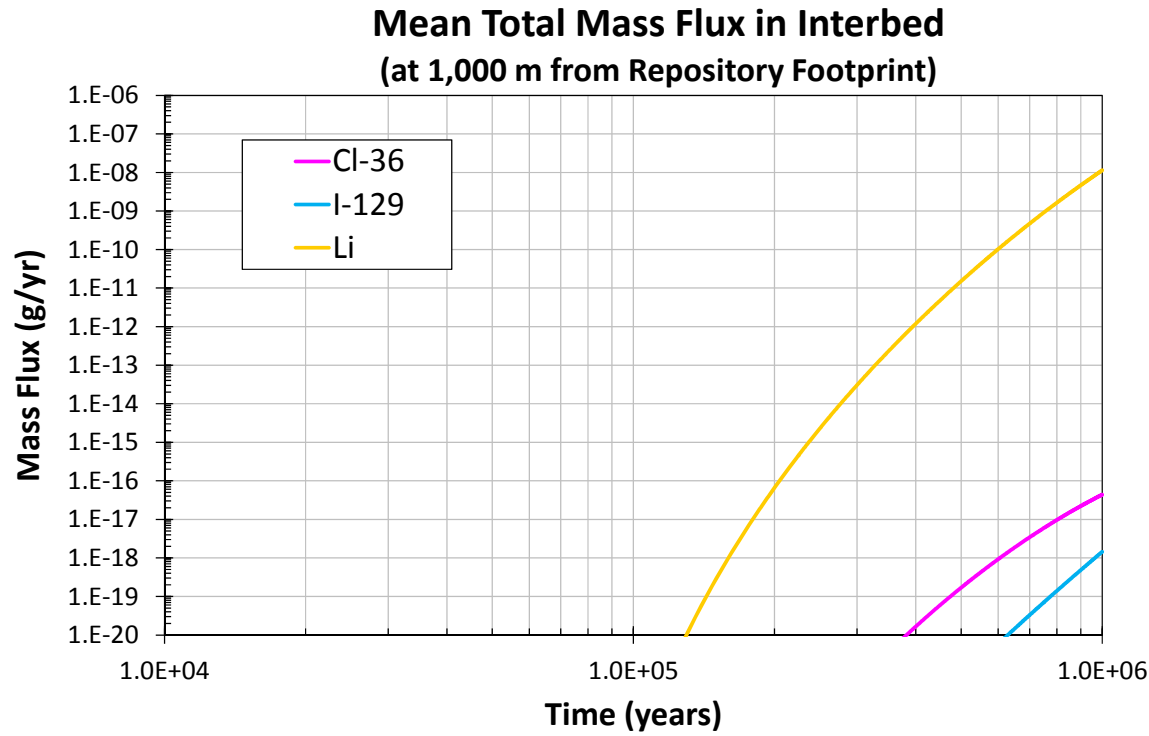
- WP fails when the overpack is corroded to a depth of 4.5 cm
- Mechanical failure of WP is assumed under lithostatic pressure
- Failure time distributions for Mark-IV and Mark-V ER salt WPs are similar

# ER Salt Waste Dissolution Model Result



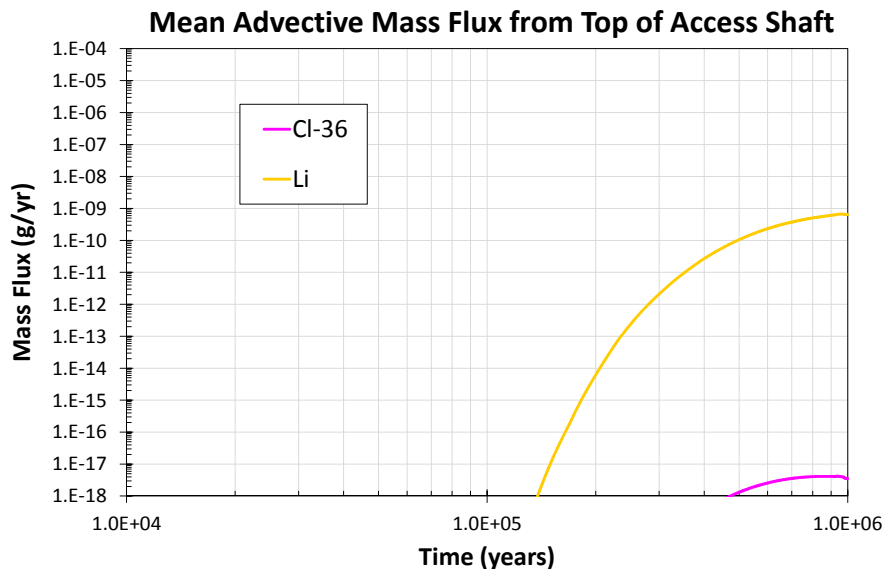
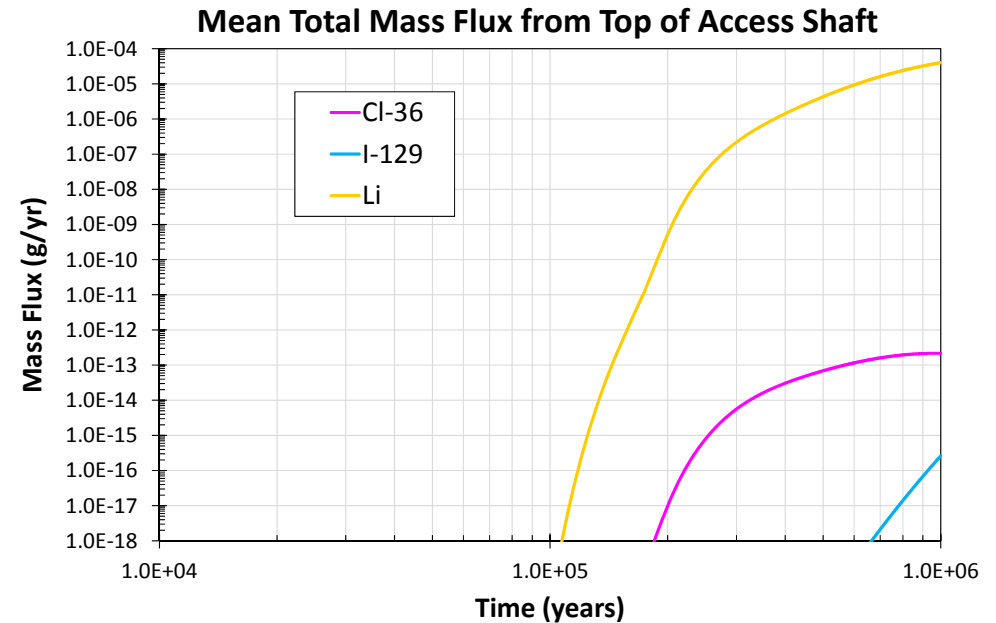
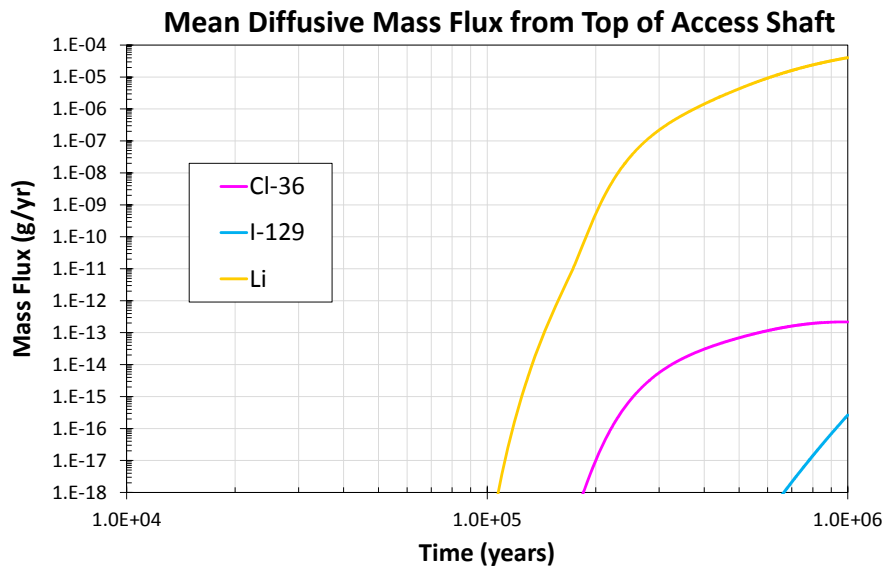
- Salt waste dissolution is congruent to LiCl dissolution
  - Salt waste dissolution and RN releases are fast
- Most released RNs are precipitated
  - Subject to solubility constraints in chemically reducing conditions (except I, C, Cs, Sr, and Ra)

# RN Releases from Far-Field Interbed



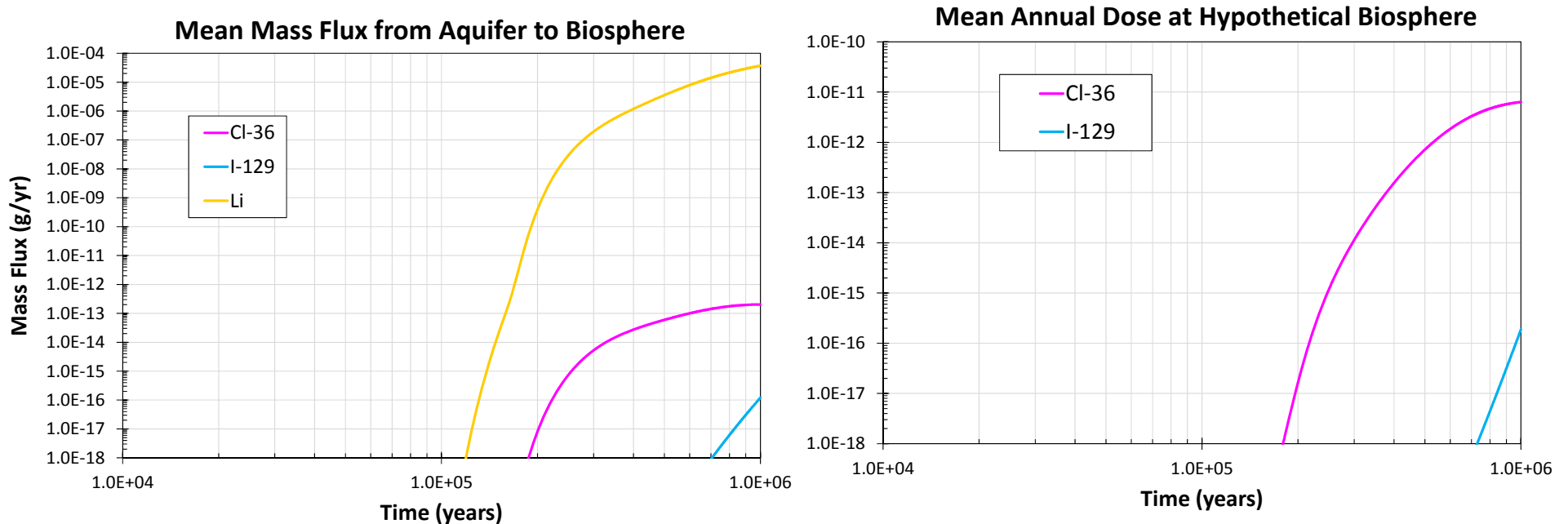
- **RN release rates in the underlying interbed at 1,000 m from the repository footprint are negligibly small**
  - No releases beyond the distance
- **RNs released in the underlying interbed remain in the interbed**
  - No hydro-geological features to connect interbed to biosphere

# RN Releases from Top of Access Shaft



- **Diffusion dominated transport in repository access shaft**
  - Very low brine flows in the access shaft
- **RN transport further retarded in the shaft by sorption**
- **Non-sorbing or weakly sorbing RNs (i.e., I-129, Cl-36) with a significant inventory are released from the shaft to overlying aquifer**

# RN Releases to Hypothetical Biosphere



- Retardation of Cl-36 and I-129 transport in the aquifer by sorption
- Release rates of RNs at the site boundary (location of hypothetical biosphere) are negligibly small
- Dose rates by the RNs at the hypothetical biosphere are negligibly small

# Summary and Conclusions

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- **Developed PA model to evaluate technical feasibility for direct disposal of ER salt waste in a generic salt repository**
  - **Implemented source-term and WP configuration specific to ER salt waste**
  - **Incorporated the latest understanding and representative geologic settings and features of generic salt disposal system processes**
- **Preliminary analysis shows ER salt waste can be disposed of safely without “extensive” treatments in a bedded salt repository (a type of salt formation in this study)**
- **Demonstrate utilization of PA tools to develop guidance for HLW waste management strategy**

# Future Work

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- **Uncertainty analysis to evaluate effect of important repository parameters to ER salt direct disposal**
  - Brine flows, overpack corrosion products pore volume, salt dissolution rate, etc.
- **Improved models for steel overpack corrosion degradation and corrosion product evolution**
  - Real time model analysis for evolution of salt precipitates, porosity, pore volume, etc.
- **Improve detailed process-level analysis for brine flows**
  - Coupled processes (T-M-H-C)
  - Effect of WP degradation and failure
  - Brine flows in disposal rooms and alcoves, and to repository shaft

# Future Work (cont'd)

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- **RN sorption on steel corrosion products mixed with degrading salt waste**
- **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
- **Improve analysis for flow and transport in generic regional aquifer**