Subsystems act as barriers in series

Near field environment ➔ Engineered barrier system ➔ Near field transport ➔ Unsaturated zone transport ➔ Saturated zone transport ➔ Scenarios

Radionuclide release rates
Radionuclide release rates
Radionuclide release rates
Radionuclide release rates to accessible environment
The PACE-90 nominal case focused on selected barriers

DOE Working Group 2 collaborated to define and analyze a source term problem

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Approach:
- What do we need to know to analyze the problem?
- Focus on the final steps leading to releases from the EBS
- Use available data and some cautious assumptions
- Boundary condition on the cautious side:
  - Assume areal average groundwater flux (Darcy) is 0.5 mm/y
What inputs are required

Input information considered

I. Hydrology at borehole scale

- General modes of water contact:
  - Seepage, dripping into borehole
    - Flowthrough container state
    - Bathtub container state
  - Static pathways for diffusion
    - Rubble in air gap
    - Rock block
"Bathtub" and "flowthrough" water contact modes

Diffusion requires a continuous water pathway
Input hydrology (continued)

• Experimental and analytical information considered:
  — Prototype and lab tests of heatup/cooldown/rewetting
  — Lab tests of effective diffusion coefficients in gravels
  — Coupled fluid and heat flow analysis
  — Single-fracture infiltration flow analysis

• We analyzed and compared flowthrough, bathtub, and rubble diffusion contacts

• We used heatup/cooldown across the repository as a control on water contact times

• Water flux variability across the repository will be added in the future

Input information considered
II. Spent fuel/groundwater interaction

• Multiple–cycle tests available
  — Uranium reaches an apparent solubility limit, but dissolution of Tc, I, Cs does not stop

• Conceptual models
  — Forward alteration of UO₂ matrix
  — Crack and grain boundary release
  — We used an upper bound on two concepts and two experiments
  — Additional tests are planned to resolve processes

• Solubilities
  — Measured and calculated
  — Solubilities of actinides are uncertain but quite low
Representative long-lived radionuclides were selected for analysis

- Tc-99, I-129, Cs-135
  - Highly soluble
  - A fraction of inventory in fuel/cladding gap
  - Retardations low (Tc, I) and high (Cs)

- Np-237
  - Low solubility
  - One predominant isotope
  - Use as a representative for other major actinides

Other conservative or cautious assumptions

- Each container is assumed to breach 300 years after it cools down below the boiling point of water
- Fuel cladding's protective effects are neglected
- Diffusion resistance inside container is neglected
Release of low-solubility Np-237 was of low amplitude, long duration

![Graph showing release of Np-237 over time with three curves: Flow, Diffusion, and Bathtub.]

Release of Tc-99 from wet waste packages was of relatively short duration and high amplitude

![Graph showing release of Tc-99 over time with three curves: Flow, Diffusion, and Bathtub.]
Diffusion-based release was lower for Cs–135 due to retardation

Source term behavior depends on radionuclide type

- **Tc–99, I–129**
  - Release can be of relatively short duration (thousands of years)
  - Limiting factors are $\text{UO}_2$ alteration rate or hydrological factors

- **Cs–135**
  - Release can be of short or long duration depending on water contact mode
  - Limiting factors are as for Tc–99 and also retardation

- **Np–237**
  - Release is of long duration, low amplitude
  - Limiting factors are solubility and hydrology
Sensitivity of our simplified model can be done by inspection in some cases

Release rate

Bathtub

Low-solubility element

\[ \text{C}_o \text{Q} \]

\[ t_{\text{fill}} \]

Flowthrough

\[ \text{C}_o \text{Q} \]

Diffusion

\[ \text{C}_o \frac{D}{L} \text{EA} \]

Further attention is directed to sensitive inputs to our inputs

Rock mineralogy

Heat transfer

Groundwater chemistry

Water flux

Waste form alteration rate

Spent fuel chemistry, physical condition, gap, crack, grain boundary enhancements

Temperature
Inputs to our inputs (continued)

- Average near-field groundwater flux
- Partial saturation in rock and rubble
- Effective diffusion coefficient
- Geometry, degraded state of borehole

The PACE-90 nominal case focused on selected barriers

- Near field environment
- Engineered barrier system
- Source term of radionuclides
- Far field environment
- Unsaturated zone transport
- Radionuclide release rates to saturated zone
Hydrologic and geochemical inputs control transport output

Hydrologic flow field

- Dispersion, diffusion, matrix-fracture exchange
- Retardation, colloids
- Source term

Transported in unsaturated zone

Time histories of release rates to saturated zone

Los Alamos National Lab is the primary source for site-specific transport processes and parameters.

Source term subsystem summary

- Source term concepts and results to PACE-90 total system assessment
- Sensitivity analysis
- Transport subsystem inputs