SAND2014-15087PE

Used Fuel Disposition Campaign

Overview of Minor Actinides Considerations for Disposal Concepts

David C. Sassani
Waste Form Performance Technical Lead
Sandia National Laboratories

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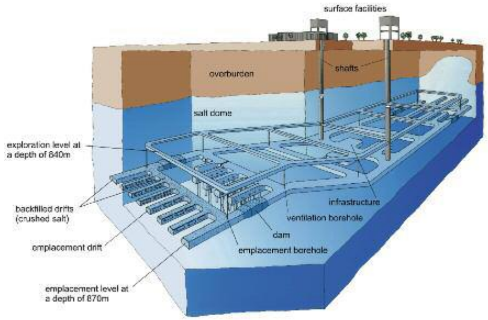
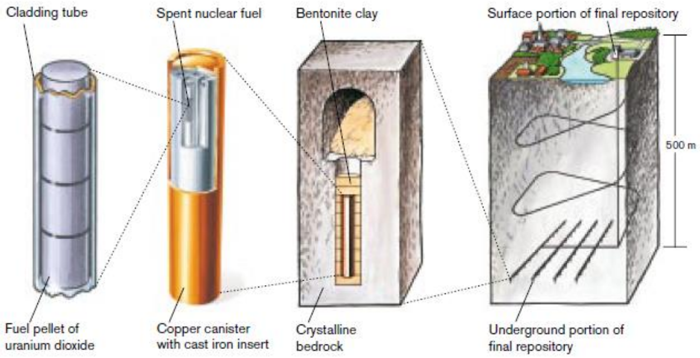
Presentation Overview

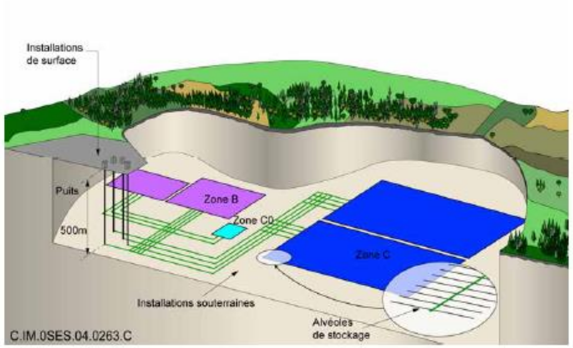
- **Acknowledge - Peter Swift, NTD UFD Campaign**
- **Overview**
  - Used Fuel Disposition Disposal Concepts
  - General Waste Form Impacts on Repository Performance and Model Concepts
- **SNF and HLW Disposal Considerations and Performance Impacts**
  - General Considerations
  - Volumes
  - Thermal
  - Risk
  - Waste Form Lifetime
- **Summary and Discussion**

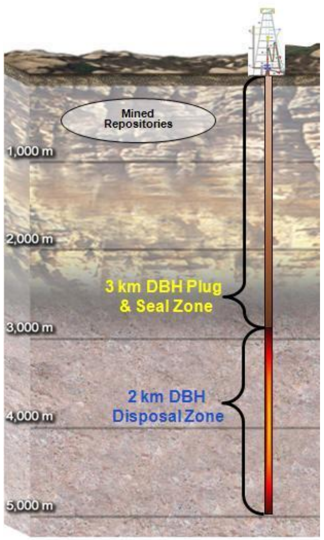
Used Fuel Disposition Campaign Disposal Research Concepts

- **Mined repositories in granitic rocks, salt, and clay/shale rocks**



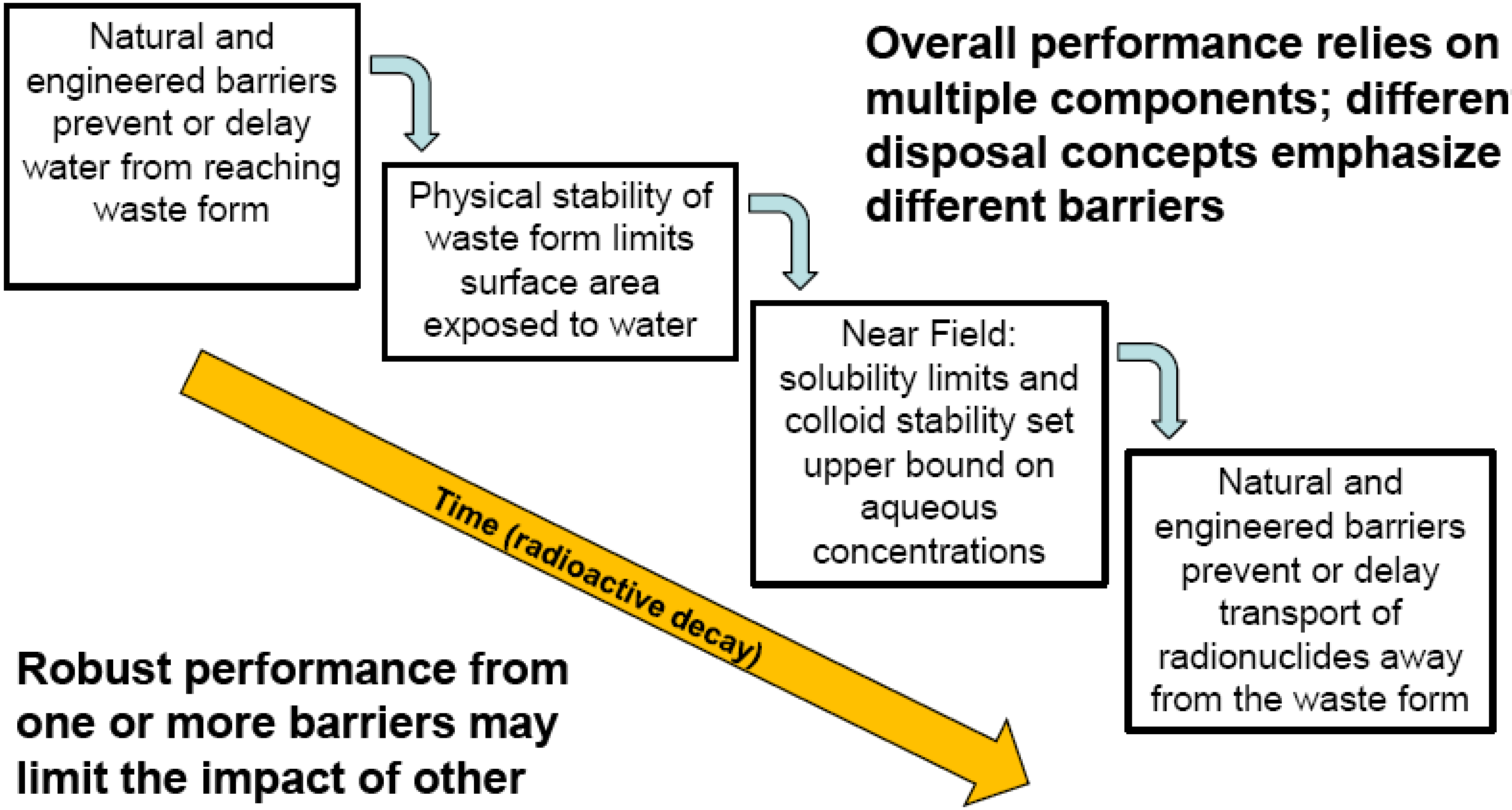






- **Deep borehole disposal concepts**

General Impacts of Waste Form on Repository Performance



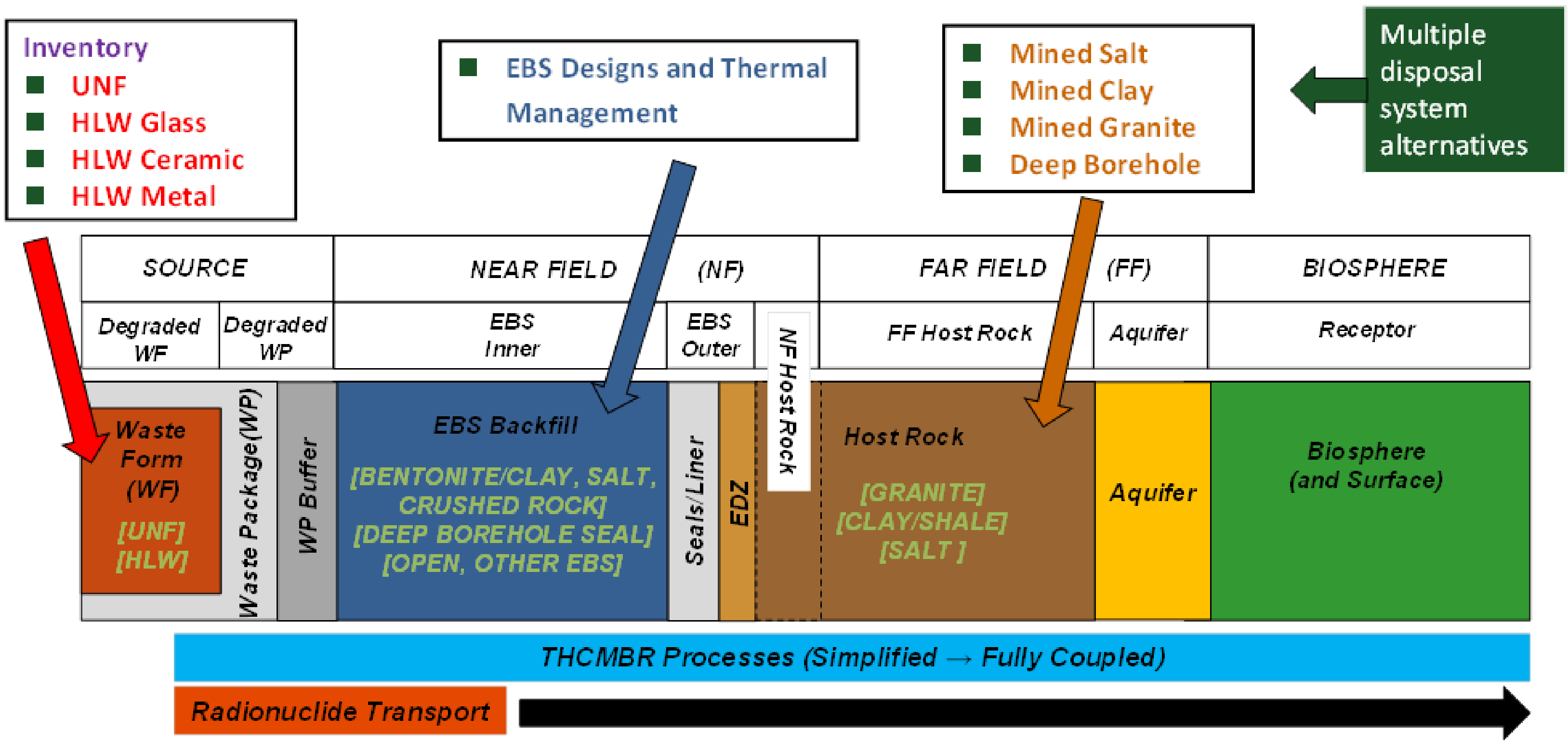
Overall performance relies on multiple components; different disposal concepts emphasize different barriers

Robust performance from one or more barriers may limit the impact of other components

Used Fuel Disposition

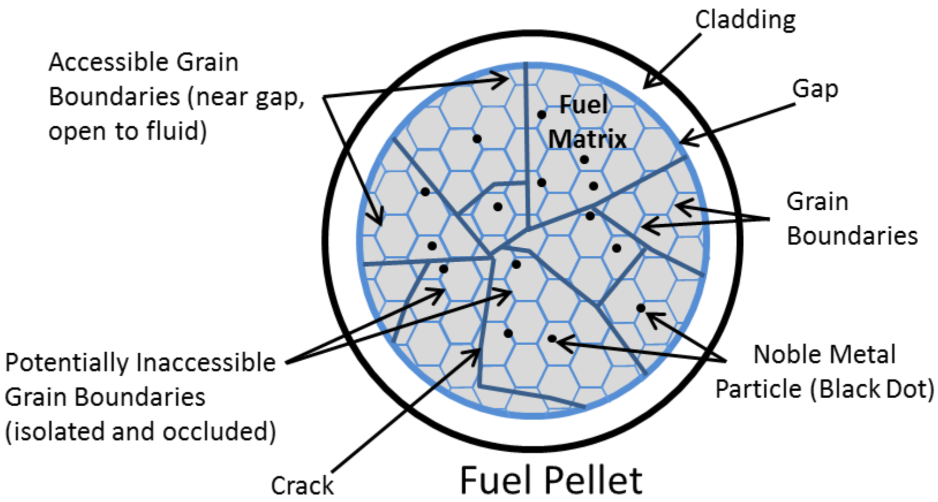
Generic Performance Assessment Model – Conceptual Framework

- Generic PA model concepts, including interfaces, features, and processes
- Range of processes and process model fidelities



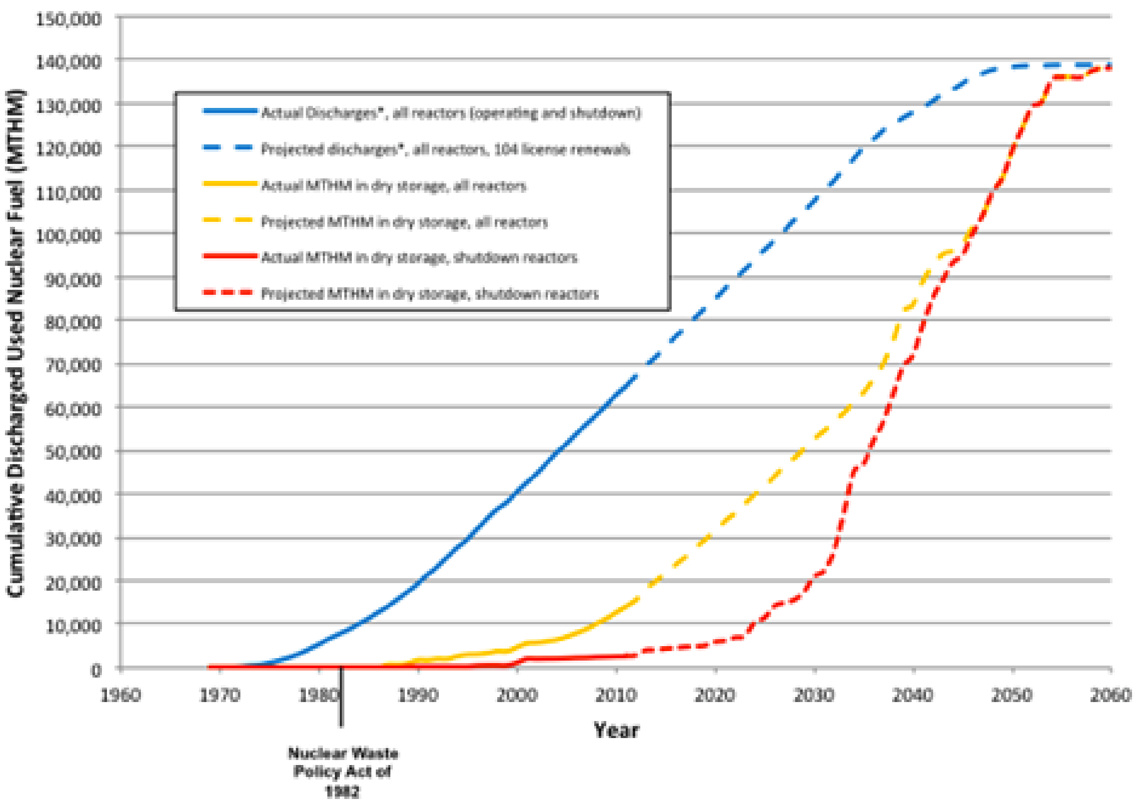
UFD&RM Model Structure and Concepts

- **Used Fuel Degradation and Radionuclide Mobilization Model Concepts**
  - The *instant release fraction* (IRF) comprised of fission products (including fission gases) located in
    - *The rod plenum regions (e.g., Kr and Xe)*
    - *The fuel gap (between pellet and cladding*
    - *The accessible grain boundaries/pellet fractures*
  - The *matrix* inventory that includes the UF matrix itself and radionuclides located in
    - *The inaccessible grain boundaries/pellet fractures*
    - *Solid solutions (e.g., Pu, Np) within the matrix*
    - *The epsilon phase (noble metal particles)*



Used Fuel Disposition

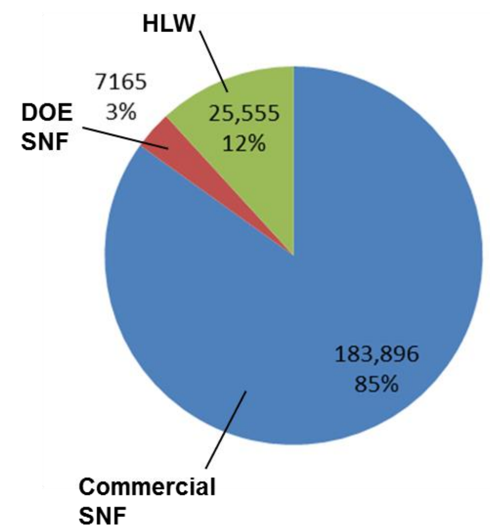
Overview of Projected SNF and HLW Amounts



Source: *Based on actual discharge data as reported on RW-859s through 12/31/02, and projected discharges, in this case for 104 license renewals

Historical and Projected Commercial SNF Discharges in the United States, showing increase of approximately 2000 metric tons per year

Projected Volumes of SNF and HLW in 2048



Volumes shown in m^3, assuming constant rate of nuclear power generation and packaging of future commercial SNF in existing designs of dual-purpose canisters

Why Reprocess Commercial Spent Fuel?

- **Solve the waste problem? No.**
  - *"all spent fuel reprocessing or recycle options generate waste streams … [and] the need for a long-term disposal solution cannot be eliminated with any foreseeable separations technology."* (BRC 2013)
- **Simplify waste management? Maybe.**
  - Reduce volume of waste requiring deep geologic disposal
  - Reduce thermal output of waste
  - Reduce toxicity of waste
  - Create more durable waste forms
- **Plutonium for mixed-oxide (MOX) reactor fuel? Maybe.**
  - Present demand for MOX fuel is limited
  - Future demand for MOX fuel predicated on
    - *Increasing reliance on nuclear power (new reactors)*
    - *Decreasing supply of uranium*

Waste Volume Considerations

- **Volume of HLW is process-dependent**
  - Existing processes can achieve 3-4x reductions in disposal volume relative to used fuel, including packaging
    - *up to 13 × with 100-yr aging period [van Lensa et al., 2010, table 7.1]*
  - Advanced processes may achieve lower volumes of HLW
- **Thermal performance, rather than waste volume, determines loading density and overall repository size in existing disposal concepts**
  - Thermal output of HLW can be engineered over a wide range, correlates inversely to volume without separation of heat-generating radionuclides
  - Existing commercial processes leave heat-generating radionuclides in the waste form
- **Reductions in the volume of waste requiring deep geologic disposal will reduce total repository cost**
  - Volume of low-level waste also contributes to total cost
- **Selection of optimal volume and thermal loading criteria will depend on multiple factors evaluated across entire fuel cycle**

Used
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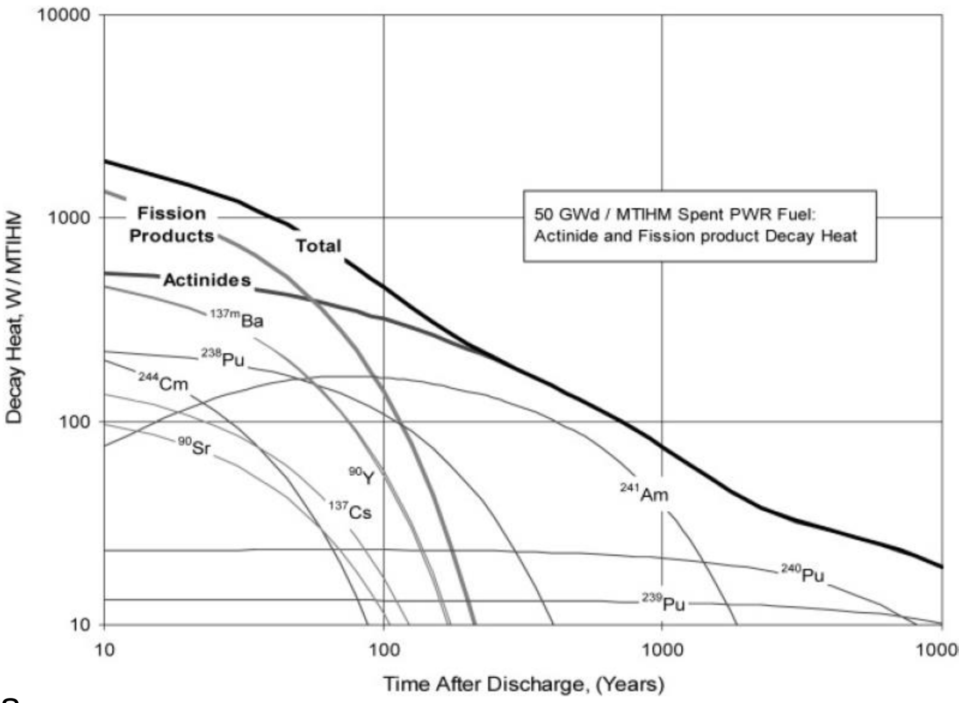
Thermal Considerations

- Repository Temperature Constraints
  - Design-specific and flexible
    - *For clay backfill/buffer*
      - Peak temperatures below boiling at the waste package surface
    - *For salt*
      - Peak temperatures in salt below 200° C
    - *For ventilated disposal concepts without backfill*
      - Peak temperatures may be dictated by material properties of host rock or engineered barriers

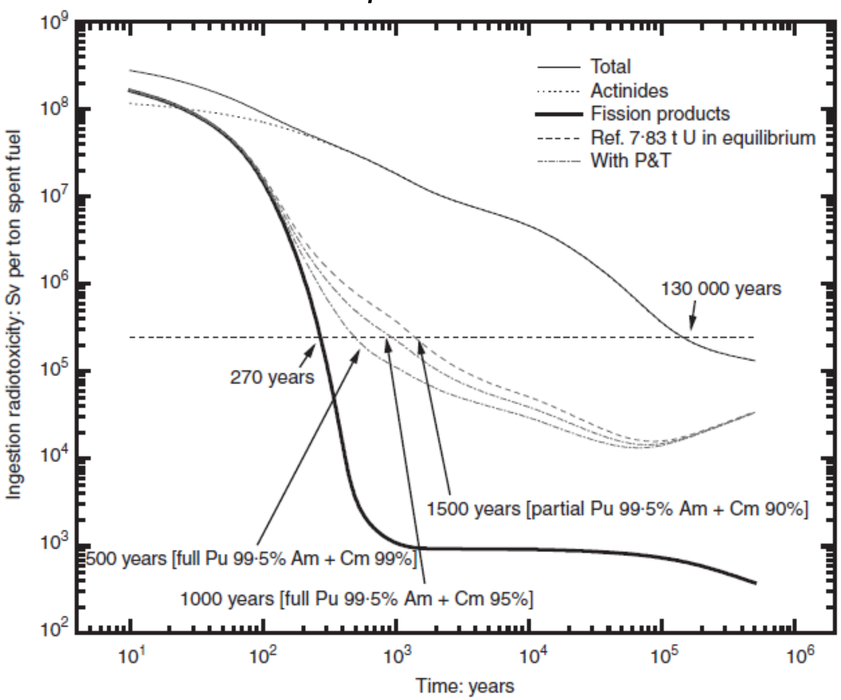


- Multiple Ways to Meet Constraints
  - Repository design
    - Size of waste packages
    - Spacing between packages
    - Thermal properties of engineered materials
  - Operational options
    - Aging
    - Ventilation
    - Load management
  - Modifications to waste forms
    - Decreasing density of fission-product and actinide loading
    - Separation of heat-generating isotopes

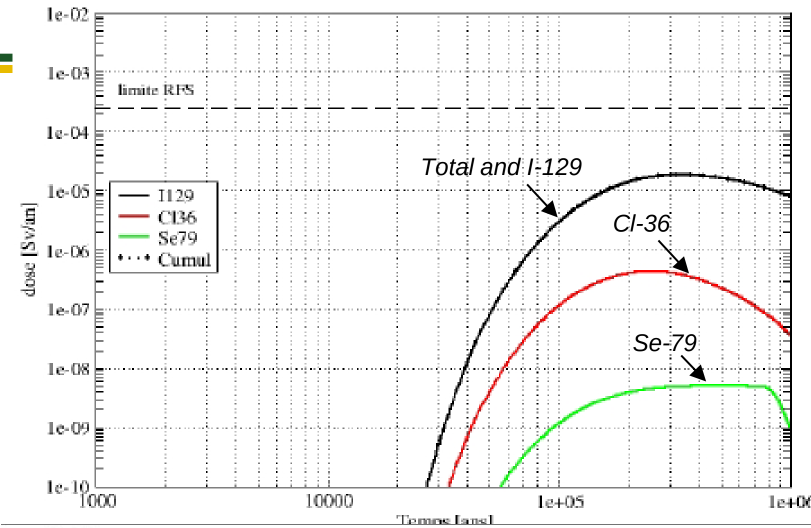
Used Fuel Disposition

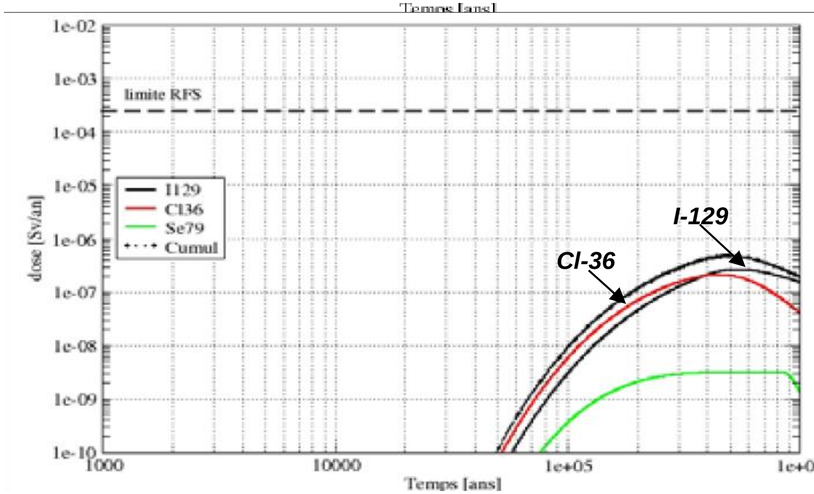
Reduce Long-term Radiation Risk?

- *Radiotoxicity (left), calculated assuming direct ingestion of radioactive waste, is dominated by actinides*
- *Estimated doses from disposal of spent fuel (upper right) and vitrified HLW (lower right) are dominated by mobile fission and activation products*



Magill et al., 2003, Nuclear Energy v. 42, p. 263-277, Figure 8; doses calculated for ingestion of 1 metric ton of spent nuclear fuel, based on ICRP-72 dose coefficients, showing reductions associated with different levels of actinide separation.





ANDRA 2005, Dossier 2005: Argile. Tome: Evaluation of the Feasibility of a Geological Repository in an Argillaceous Formation, Figure 5.5-18, SEN million year model, CU1 spent nuclear fuel and Figure 5.5-22, SEN million year model, C1+C2 vitrified waste

Used Fuel Disposition

Reduce Long-term Risk by Extending Waste Form Lifetime?

- **Example from Spent Fuel Disposal Analyses at Forsmark, Sweden**
  - Fractional dissolution rate range 10^{-6}/yr to 10^{-8}/yr
    - *Corresponding fuel lifetimes: ~ 1 Myr to 100 Myr*
    - *Dissolution rates for oxidizing conditions (not anticipated), up to 10^{-4}/yr*
  - Uncertainty in fuel dissolution rate is dominant contributor to uncertainty in modeled total dose estimates

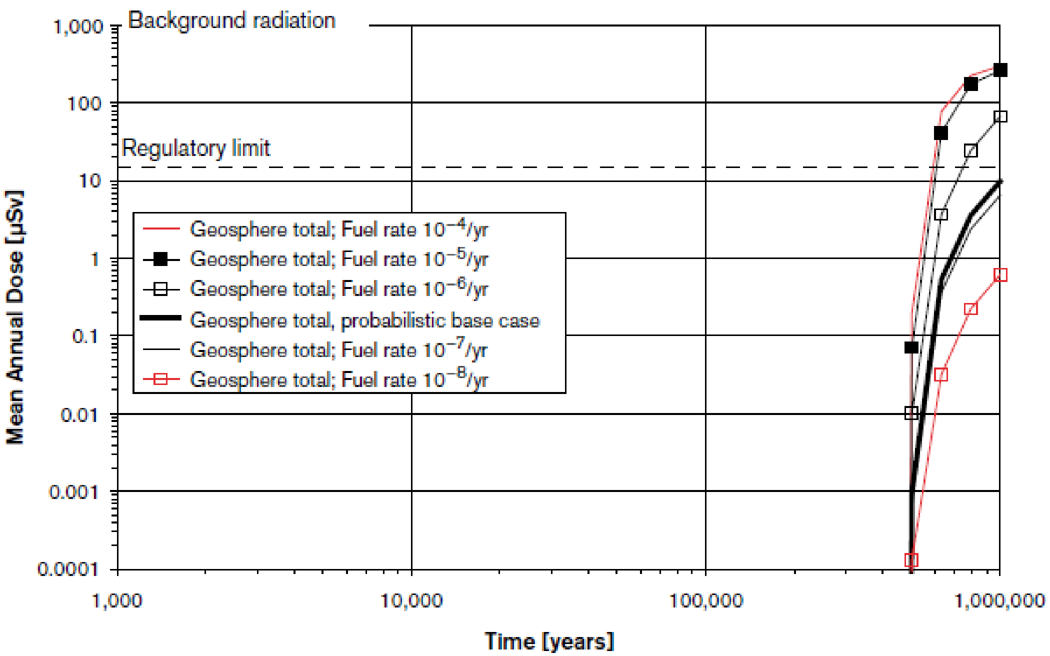


Figure 10-44. Sensitivity of the base case result to the fuel dissolution rate. Semi-correlated hydro geological DFN model for Forsmark. 1,000 realisations of the analytic model for each case.

Source: SKB 2006, Long-term Safety for KBS-3 Repositories at Forsmark and Laxemar—a First Evaluation, TR-06-09, section 10.6.5

Also, SKB 2006, Fuel and Canister Process Report for the Safety Assessment SR-Can, TR-06-22, section 2.5.5

Will Reprocessing Solve Waste Management?

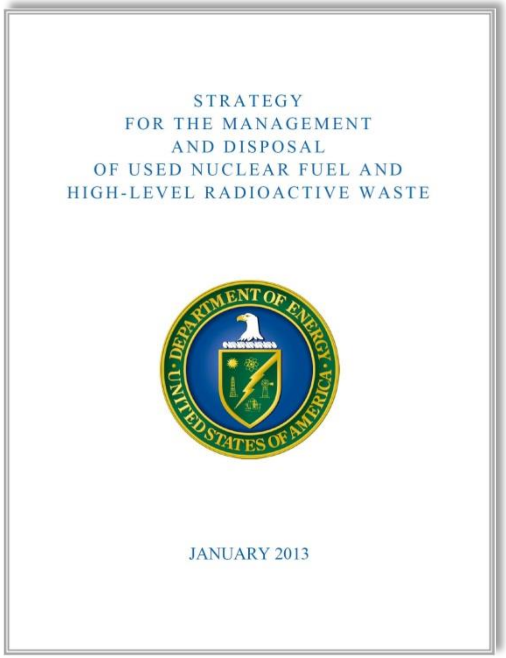
- **Manage the existing fuel cycle first**
  - Technical solutions for disposal are available now
- **Reprocessing could increase confidence for future fuel cycles**
  - Reduce actinide content of waste
    - *But primary contributor to long-term risk is I-129*
  - Reduce heat load
    - *Fission products are the primary early-time heat source*
    - *Thermal loading will have a significant impact on repository design and operations regardless*
      - Ventilation, low emplacement density, century-scale storage
  - Reduce volume of waste requiring geologic disposal
    - *Inverse relationship with thermal load*
    - *Net reduction of repository disposal volume from processing could be on the order of 3-4x, more with extended surface storage*
  - Provide longer-lived waste forms
    - *Potential for increased confidence in repository performance*

Current versus Future Spent Fuel

- **U.S. policy has allowed commercial reprocessing since 1981**
  - Decision is fundamentally tied to economic considerations
- **The DOE has concluded that there is no reason to retain existing commercial spent fuel for reprocessing**
  - Future discharges (2000 metric tons/year for the next 40 years) are more than sufficient to serve as feedstock for any future reprocessing enterprise

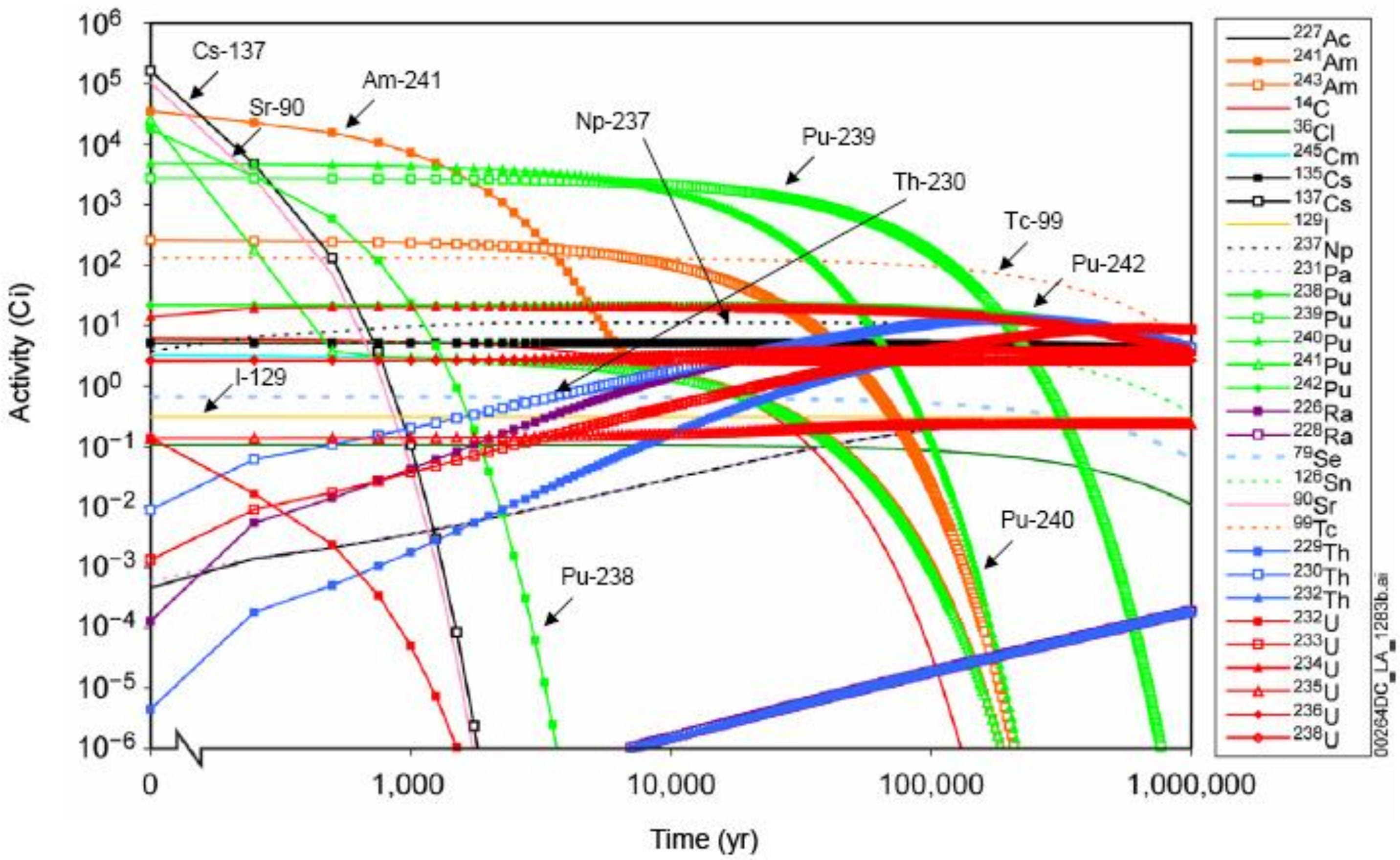
"98 percent of the total current inventory of commercial used nuclear fuel by mass can proceed to permanent disposal"

Source: DOE 2013, "Strategy for the Management and Disposal of Used Nuclear Fuel and High-Level Radioactive Waste"



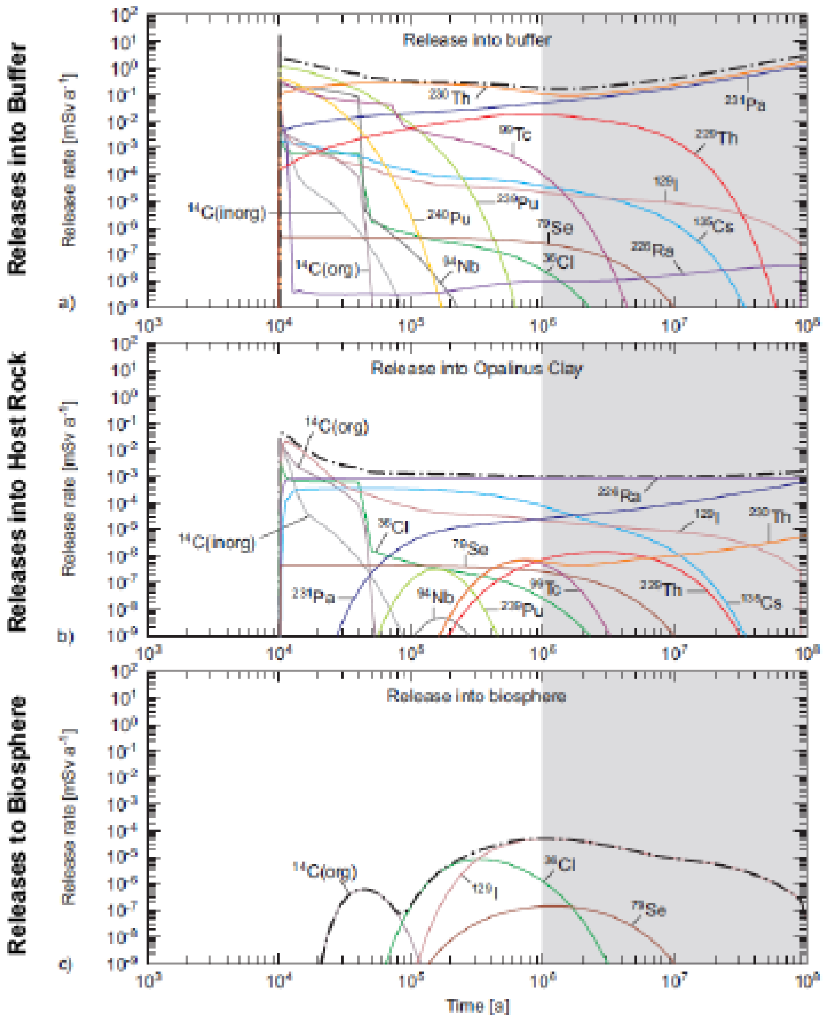
Backup Materials

Commercial Spent Nuclear Fuel Decay



DOE/RW-0573 Rev 0, Figure 2.3.7-11, inventory decay shown for an single representative Yucca Mountain used fuel waste package, as used in the Yucca Mountain License Application, time shown in years after 2117.

Contributors to Total Dose: Opalinus Clay (Switzerland)



Releases from spent fuel dominated by early spike of I-129 and long-lived actinides (Th-230, Pa-231)

Releases from clay buffer dominated by relatively more mobile Ra-226 and I-129

Releases to biosphere dominated by I-129, Cl-36, C-14, and Se-79

NAGRA 2002, *Project Opalinus Clay Safety Report: Demonstration of disposal feasibility for spent fuel, vitrified high-level waste and long-lived intermediate level-waste (Entsorgungsnachweis)*, Technical Report 02-05, Figure 6.5-1

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