Geologic Repositories and the Fuel Cycle

NPRE412

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Outline

Repository Components

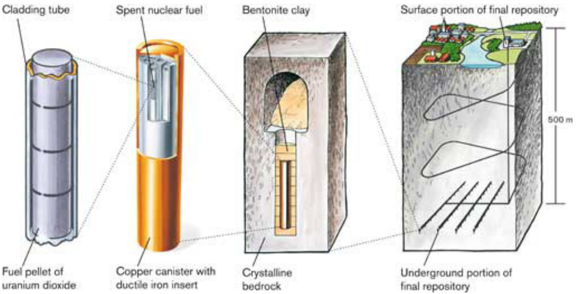


Figure: Geologic disposal systems typically employ engineered barrier systems as well as natural barrier systems. This is a Swedish concept in granite [1].

Engineered Barriers : Waste Forms

The first line of defense is the waste form.

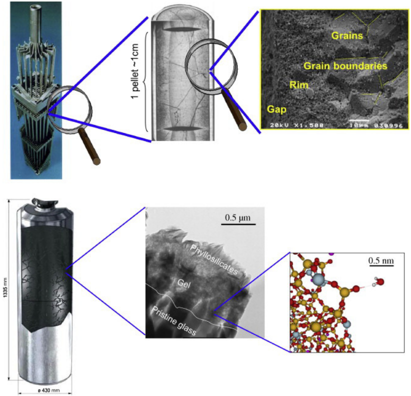


Figure: A comparison of uranium oxide and borosilicate glass waste forms [12].

Engineered Barriers : Waste Packages

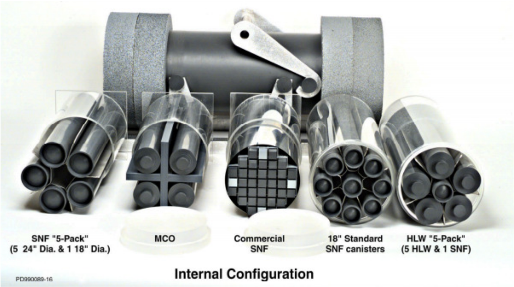


Figure: Conceptual mockup of waste packages around waste forms [2].

Engineered Barriers : Disposal Cask

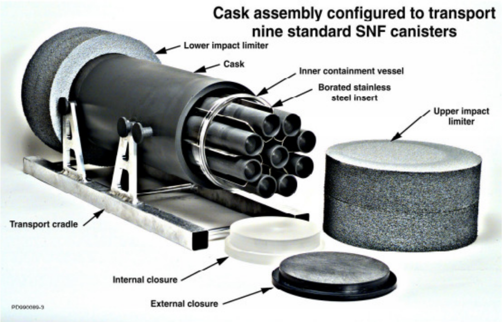
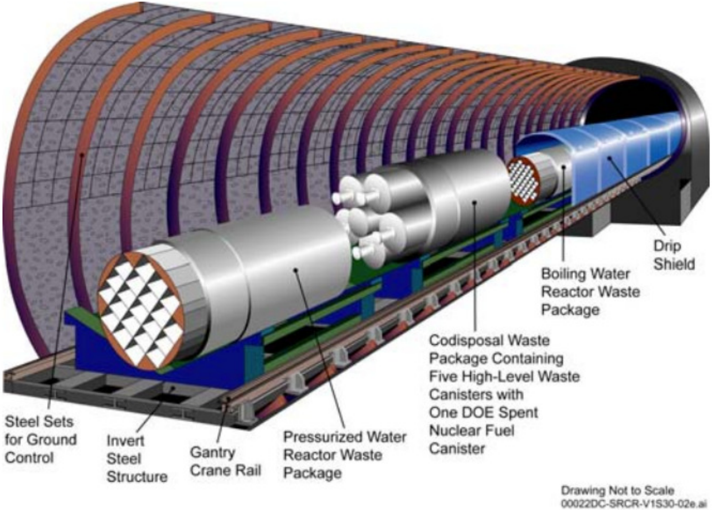


Figure 3. Conceptual design model.

Figure: Conceptual mockup of a transport and disposal cask [2].

Engineered Barriers : Tunnel



Natural Barrier : Geology

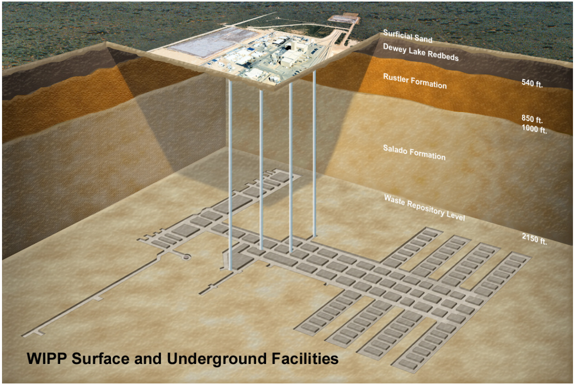
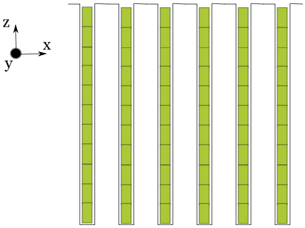


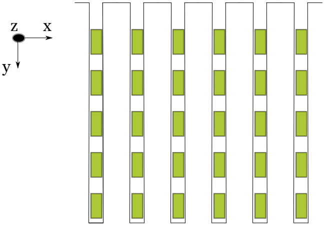
Figure: The Waste Isolation Pilot Plant has many geologic layers above the salt bed [5].

Repository Layouts

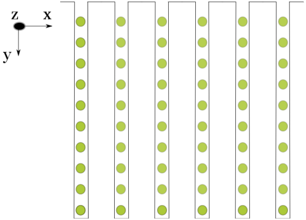
Deep Boreholes



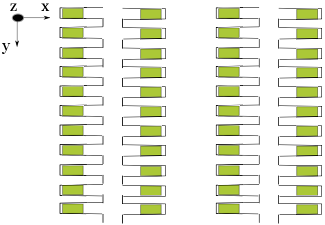
Horizontal In-Tunnel



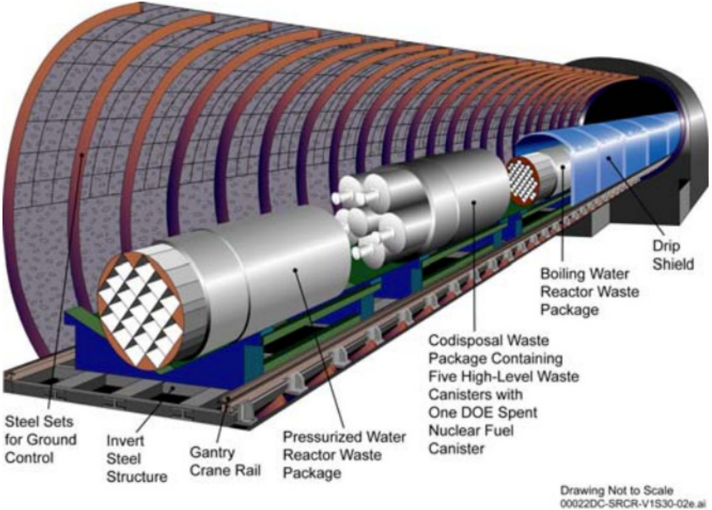
Vertical In-Tunnel



Alcoves



Unsaturated, Ventilated Concepts



Saturated , Enclosed Concepts

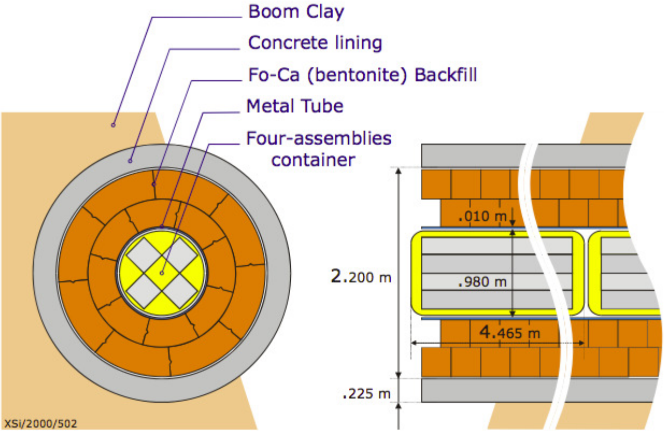


Figure: The Belgian reference concept in Boom Clay is backfilled very soon after waste emplacement without a ventilation period and is located below the water table [14].

Tuff (Yucca) Disposal Environments

Figure: Yucca Mountain is in southern Nevada [10].

Alternative Disposal Geology Options

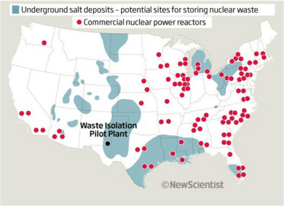


Figure: U.S. Salt Deposits, ref. [9].

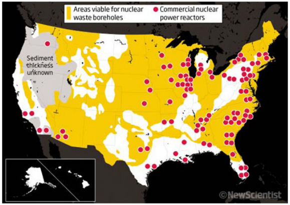


Figure: U.S. Crystalline Basement, ref. [9].

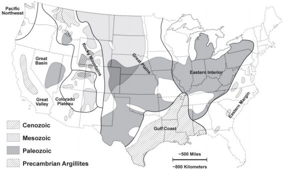


Figure: U.S. Clay Deposits, ref. [6].

Figure: U.S. Granite Beds, ref. [3].

Clay Disposal Environments

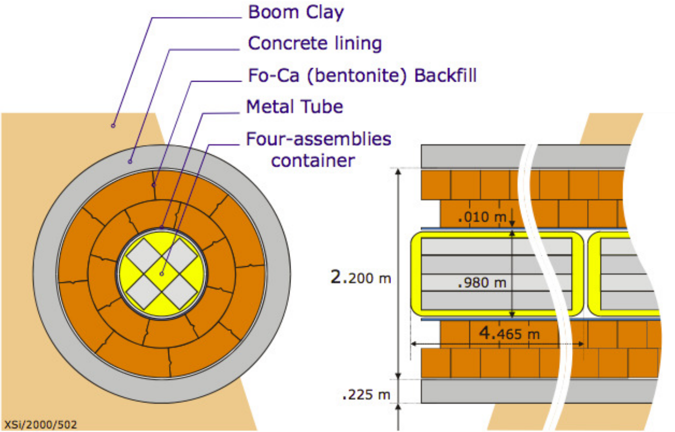


Figure: Belgian reference concept in Boom Clay [14].

Granite Disposal Environments

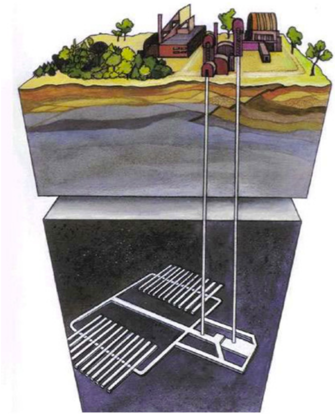


Figure: Czech reference concept in Granite [14].

Salt Disposal Environments

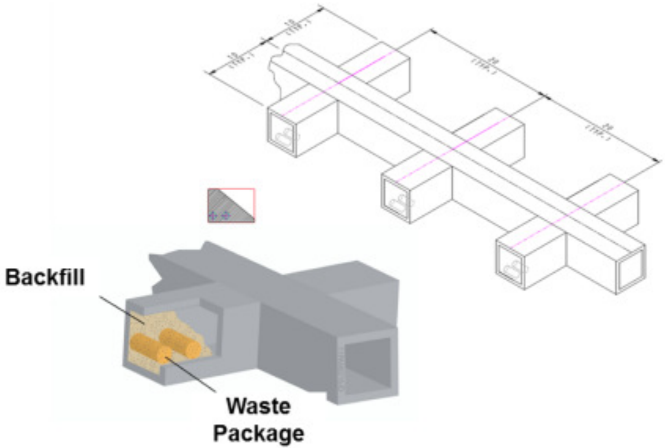


Figure: DOE-NE Used Fuel Disposition Campaign concept in Salt [8].

Salt Disposal Environments

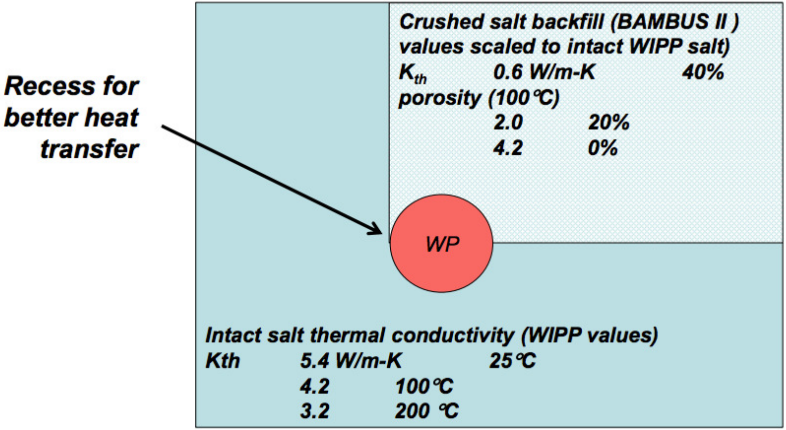


Figure: DOE-NE Used Fuel Disposition Campaign concept in Salt [8].

Deep Borehole Disposal Environment

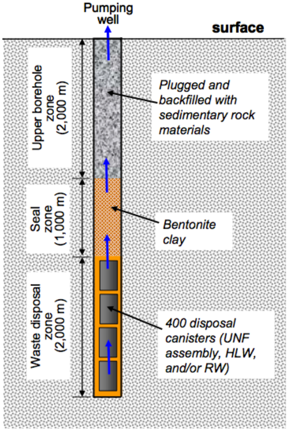


Figure: DOE-NE Used Fuel Disposition Campaign Deep Borehole concept [8].

Performance Metrics

- Dose
- Environmental Release
- Repository Footprint
- Cost
- ...

Thermal Capacity in Various Geologies

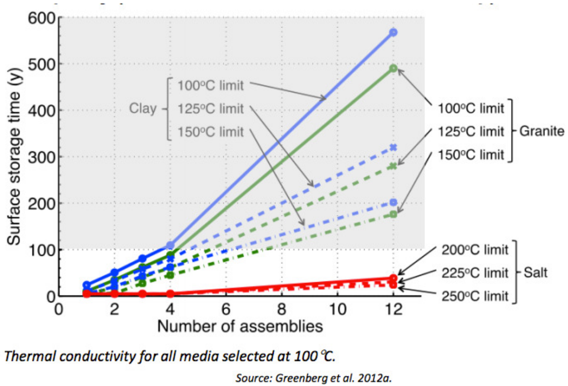


Figure: The varying thermal limits, thermal conductivities, and thermal diffusivities of various geologies result in differing heat capacities to similar waste [7].

Release Mechanisms

- Human Disruption
- Natural Disruption
- Barrier Dissolution
- Advection
- Diffusion
- Sorption
- Solubility Limitation
- ...

Solubility Sensitivity In A Clay Model

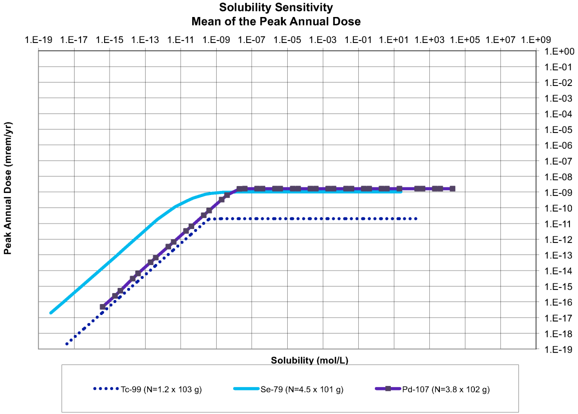


Figure: Solubility limit sensitivity. The peak annual dose due to an inventory, N, of each isotope.

Retardation Sensitivity In A Clay Model

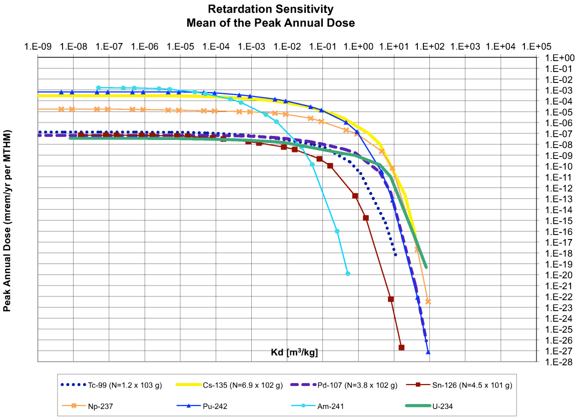


Figure: K_d sensitivity. The peak annual dose due to an inventory, N, of each isotope.

Example : Vertical Advective Velocity and Diffusion Coefficient

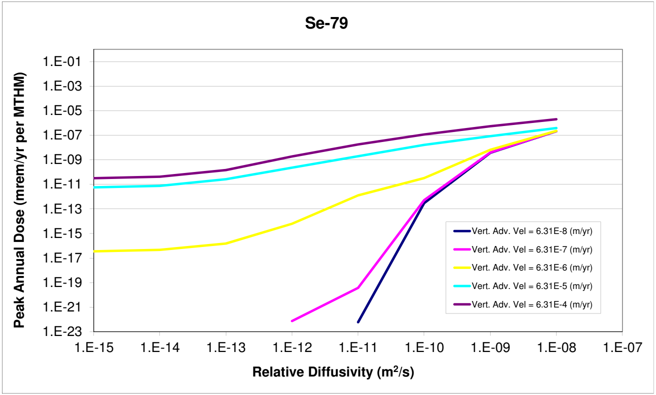


Figure: ^{79}Se. Se is non sorbing, but solubility limited in clay. For low vertical advective velocity, the system is diffusion dominated.

Example : Vertical Advective Velocity and Diffusion Coefficient

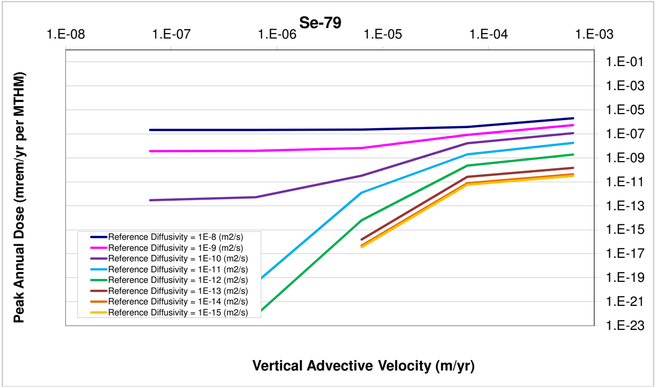


Figure: ^{79}Se. *Se* is non sorbing, but solubility limited in clay. For high vertical advective velocity, the diffusivity remains important even in the advective regime as spreading facilitates transport in the presence of solubility limited transport.

Heat Contributors In PWR SNF

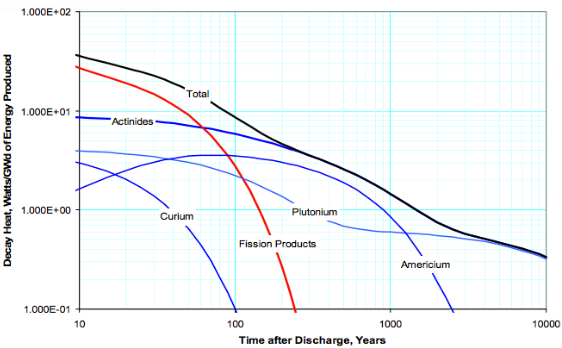


Figure: Heat contributors in a canonical PWR fuel[15].

Heat Contributors in PWR SNF

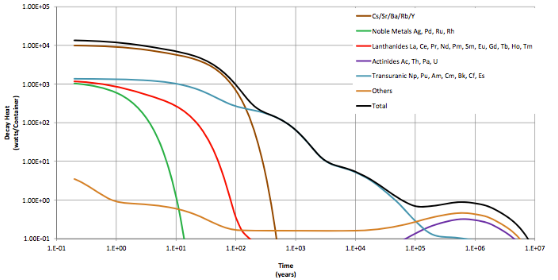


Figure 4-1 Borosilicate Glass Decay Heat Generated by Co-Extraction Processing of 51 GWd/MT 5 Year Cooled PWR Fuel

Figure: Heat contributors in the primary result of a once through PWR fuel cycle [4].

Heat Contributors in LWR Recycled MOX

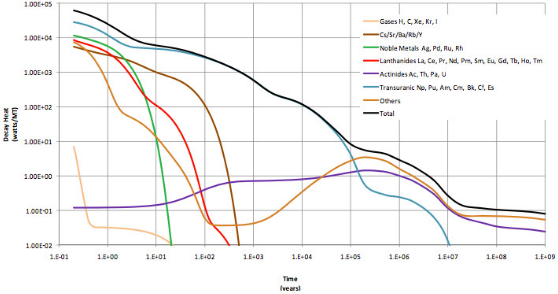


Figure 5-1 Mixed Oxide Fuel 50 GWd/MT Used Fuel Decay Heat

Figure: Heat contributors in the primary result of MOX recycling in an LWR [4].

Heat Contributors After NUEX Recycling

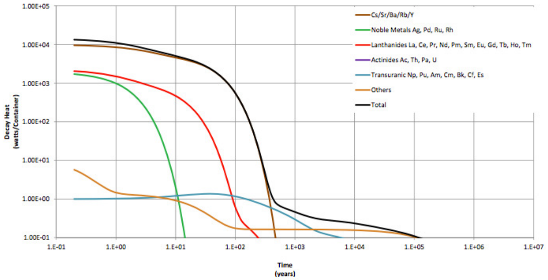


Figure 4-5 Borosilicate Glass Decay Heat Generated by New Extraction Processing of 51 GWd/MT 5 Year Cooled PWR Fuel

Figure: Heat contributors in the primary result of the NUEX extraction process[4].

Heat Contributors After COEX Recycling

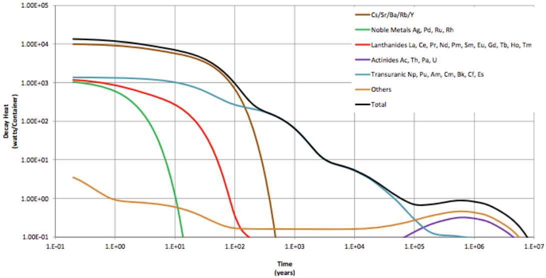


Figure 4-1 Borosilicate Glass Decay Heat Generated by Co-Extraction Processing of 51 GWd/MT 5 Year Cooled PWR Fuel

Figure: Heat contributors in the primary result of the COEX extraction process[4].

Summary: Heat Contributing Isotopes in Various Fuel Cycles

Dominant thermal contributors vary among fuel cycles.

- Recycling schemes are likely to reduce transuranics and actinides.
- Fission products such as Cs and Sr are powerful heat contributors in the first 500 years, when capacity limiting peak heat is likely to occur in many geologies.
- Transuranics, Pu, Np, Am, and Cm are dominant long term heat contributors. Some extraction processes are more successful at removing those from the waste stream.

Dose Contributors, PWR SNF In Yucca

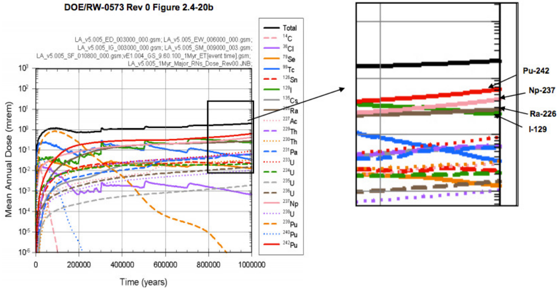
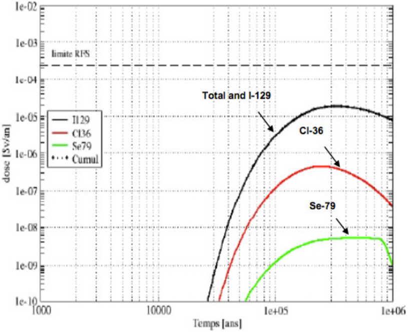


Figure: Dose contributors expected in the Yucca Mountain repository [13]. In the oxidizing environment at Yucca mountain, actinides such as ^{242}Pu and ^{237}Np dominate dose contribution. We also see that long-lived, highly soluble ^{129}I and highly soluble ^{226}Ra are also primary dose contributors.

Dose Contributors, PWR SNF In Clay



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**

Figure: Dose contributors expected in a clay repository concept [13]. Primary contributors are highly soluble, long lived isotopes ^{129}I, ^{36}Cl, and ^{79}Se .

Dose Contributors, PWR SNF In Granite

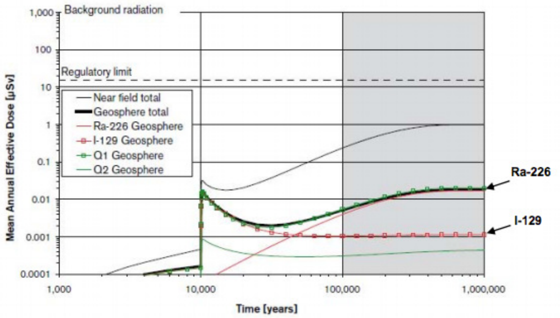


Figure 10-18. The Forsmark pinhole failure base case (geosphere total, i.e. LDF values applied to releases from the far-field model) decomposed with respect to dominant nuclides (Ra-226 and I-129) and release paths (Q1 and Q2). The effect of discarding geosphere retention is also shown (near field total, i.e. LDF applied to releases from the near field model). 10,000 realisations analytic model.

SKB 2006, *Long-term Safety for KBS-3 Repositories at Forsmark and Laxemar—a First Evaluation*, TR-06-09, Figure 10-18

Figure: Dose contributors expected in a granite repository concept [13]. Primary contributors in this more advective system are the most mobile products at the time of waste package failure. ^{129}I is always a primary contributor.

Summary: Dose Contributing Isotopes in Various Geologies

Dominant dose contributors vary among geologies due to both **water chemistry (sorption, solubility)** and **transport regime (diffusive, advective)**.

- Long lived, highly soluble, non sorbing ^{129}I is a dominant long-term contributor in all geologies.
- In a tuff geology like Yucca Mountain, which is oxidizing with advective transport, actinides dominate in addition to ^{129}I.
- In granite, a typically reducing geology with advective release pathways, mobile ^{226}Ra may be important in addition to ^{129}I.
- In primarily diffusive salt and clay geologies, long-lived, highly soluble, non-sorbing fission and activation products (^{129}I, ^{36}Cl, ^{79}Se) dominate.

Volume

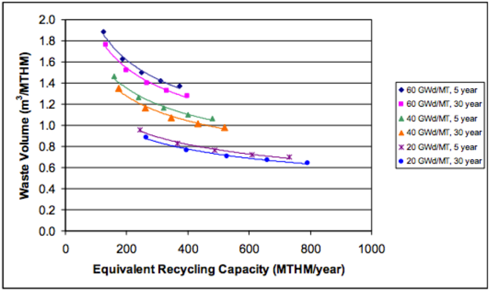


Figure 5-3 Annual Greater Than Class C Waste Volume Relative to Facility Capacity

Figure: Recycling strongly affects high level waste volumes[4].

Conclusion

Thanks!
Feel free to direct questions to huff2@wisc.edu.

References I

[1] Svensk karnbranslehantering AB.
Long-term Safety for KBS-3 Repositories at Forsmark and Laxemar-a First Evaluation: Main Report of the SR-Can Project.
SKB, November 2006.

[2] T.L. Bridges, A.L. Lengyel, D.K. Morton, and D.L. Pincock.
Standardized DOE spent nuclear fuel canister and transportation system for shipment to the national repository.
Tucson, February 2001.

[3] J. B. Bush.
Economic and technical feasibility study of compressed air storage.
Report ERDA, page 7676, 1976.

[4] Joe Carter, Robert Jones, and Alan Luptak.
US radioactive waste inventory and characteristics related to potential future nuclear energy systems.
Technical Report FCRD-USED-2011-000068, Rev 2, May 2011.

[5] DOE.
WIPP hazadous waste facility permit community relations plan, 2013.

References II

[6] Serge Gonzales and Kenneth Sutherland Johnson.
Shales and other argillaceous strata in the united states.
Technical report, Earth Resource Associates, Inc., Athens, GA (USA), 1985.

[7] Harris Greenberg, James Blink, Massimiliano Fratoni, Mark Sutton, and Amber Ross.
Application of analytical heat transfer models of multi-layered natural and engineered barriers in potential high-level nuclear waste repositories.
In *WM2012*, Phoenix, AZ, March 2012.
LLNL-CONF-511672.

[8] E Hardin, J Blink, Harris Greenberg, Mark Sutton, Massimo Fratoni, Joe Carter, Mark Dupont, and Rob Howard.
Generic repository design concepts and thermal analysis - 8.8.2011 draft.
Technical Report FCRD-USED-2011-000143, Department of Energy Office of Used Fuel Disposition, Sandia, August 2011.

[9] NewScientist.
Where should the US store its nuclear waste?
NewScientist, April 2011.

[10] OMB.
Yucca mountain 2.jpg, August 2006.

References III

[11] Mark Peters.
What's next for used nuclear fuel and nuclear waste management policy?, January 2013.

[12] Christophe Poinssot and Stphane Gin.
Long-term behavior science: The cornerstone approach for reliably assessing the long-term performance of nuclear waste.
Journal of Nuclear Materials, 420(13):182–192, January 2012.

[13] Peter Swift and Mark Nutt.
Applying insights from repository safety assessments.
In *Proceedings of 11th Information Exchange Meeting on Partitioning and Transmutation*, San Francisco, CA, October 2010. OECD-NEA.

[14] W. von Lensa, R. Nabbi, and M. Rossbach.
RED-IMPACT Impact of Partitioning, Transmutation and Waste Reduction Technologies on the Final Nuclear Waste Disposal.
Forschungszentrum Julich, 2008.

[15] Roald Wigeland.
Relationship between geologic disposal characteristics and advanced nuclear fuel cycles with partitioning and transmutation, November 2010.