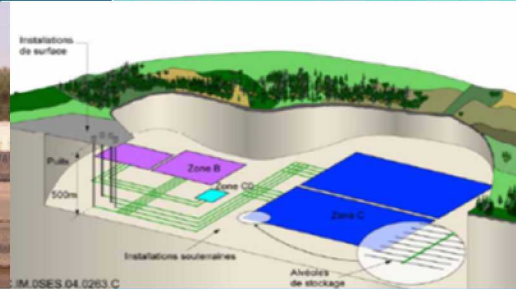


# Observations on the United States R&D Program for Deep Geologic Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste



PRESENTED BY

Peter Swift, Senior Scientist

Goldschmidt2018

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SWIFT GOLDSCHMIDT2018 AUGUST  
2018



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# Outline

- Status of the US program
- Options for geologic disposal in the US and other nations

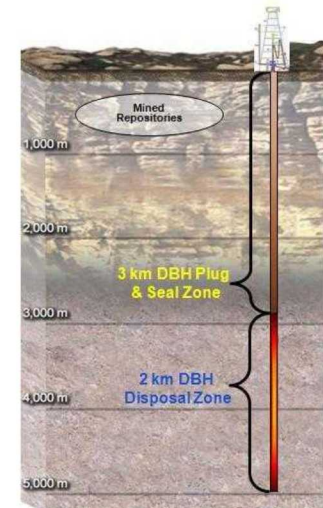
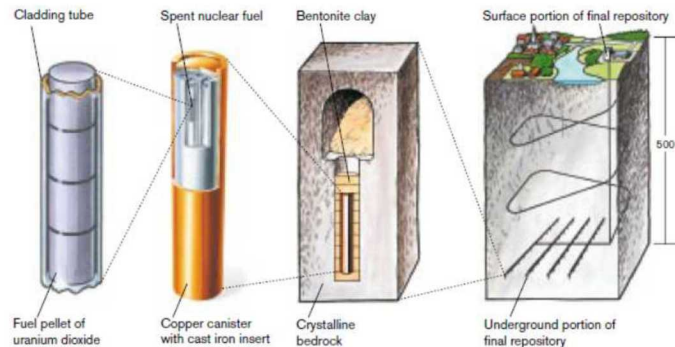
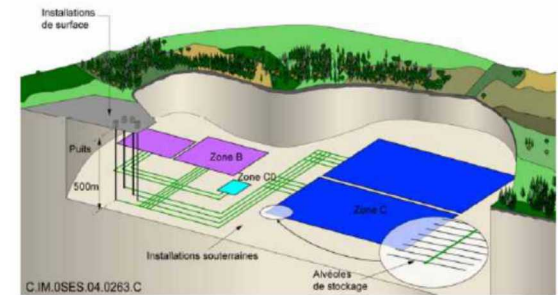
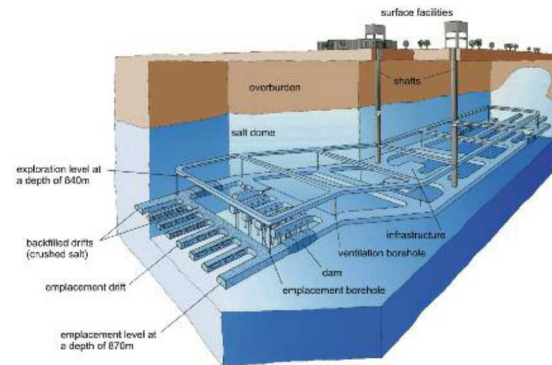
# Spent Nuclear Fuel and High-Level Radioactive Waste Disposal: The Goal

“There has been, for decades, a worldwide consensus in the nuclear technical community for disposal through geological isolation of high-level waste (HLW), including spent nuclear fuel (SNF).”

“Geological disposal remains the only long-term solution available.”

National Research Council, 2001

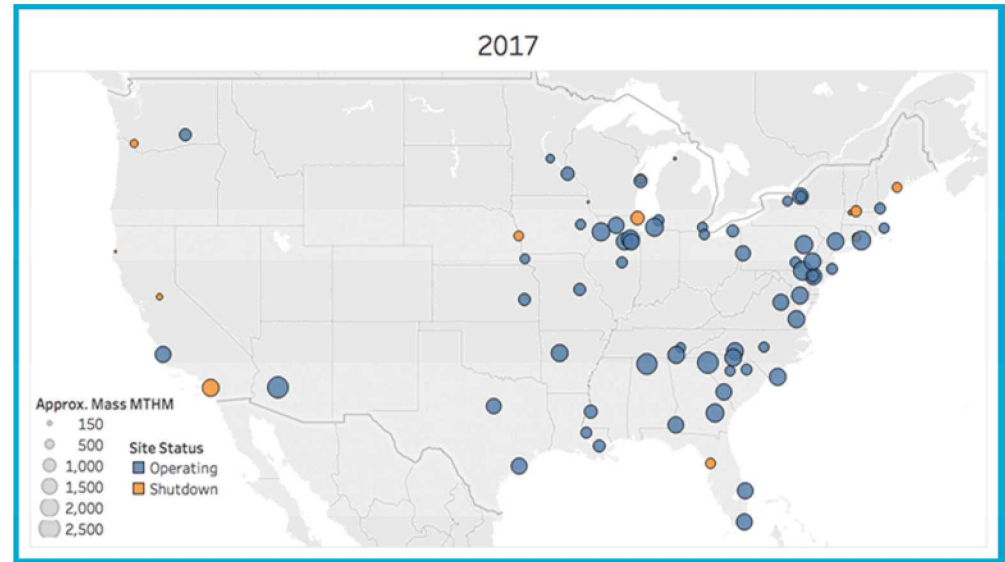
*Deep geologic disposal has been planned since the 1950s*



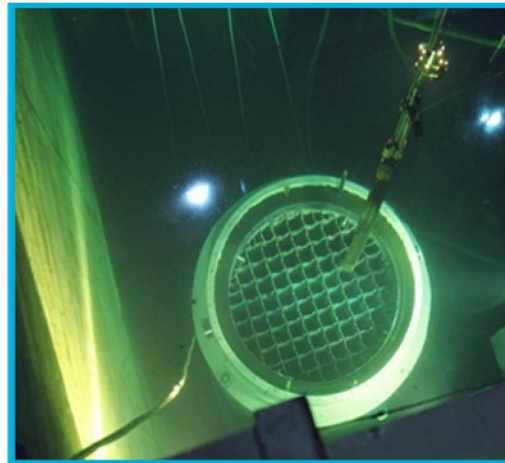
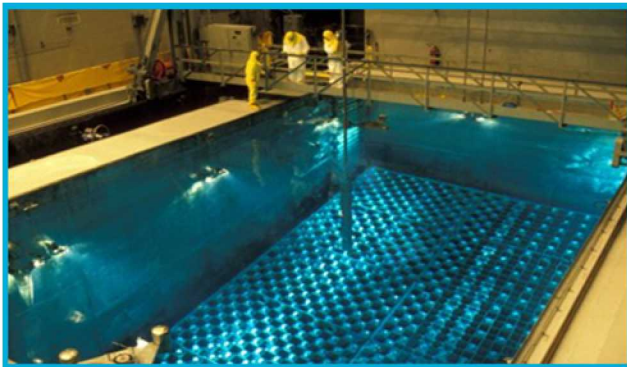
# Geologic Disposal in the US: The Reality

## Commercial SNF is in Temporary Storage at 75 Reactor Sites in 33 States

- Pool storage provides cooling and shielding of radiation
  - Primary risks for spent fuel pools are associated with loss of the cooling and shielding water
- US pools have reached capacity limits and utilities have implemented dry storage
- Some facilities have shutdown and all that remains is “stranded” fuel at an independent spent fuel storage

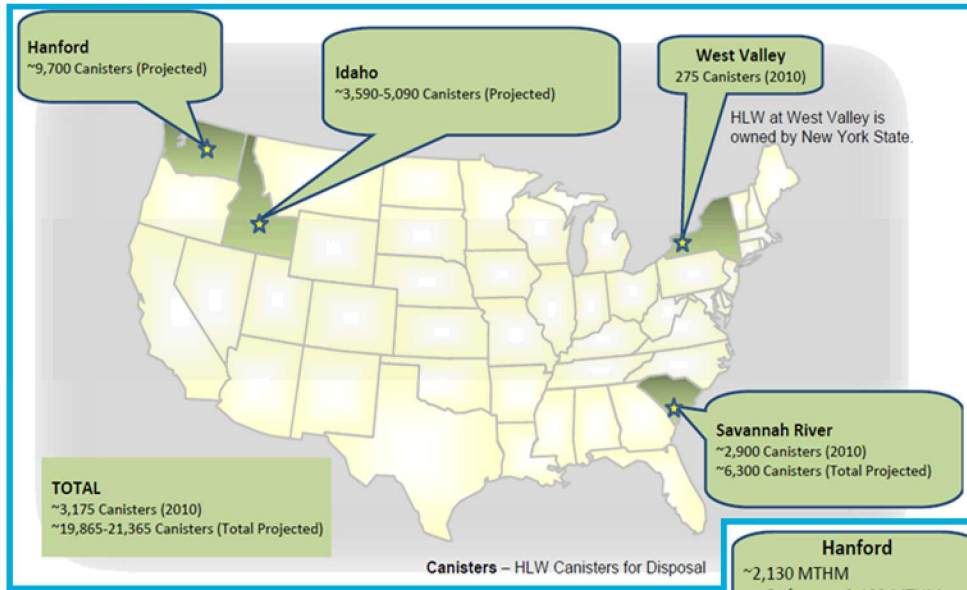


Map of the US commercial SNF storage from Bonano et al. 2018



# Geologic Disposal in the US: The Reality (cont.)

*DOE-managed SNF and HLW is in Temporary Storage at 5 Sites in 5 States*

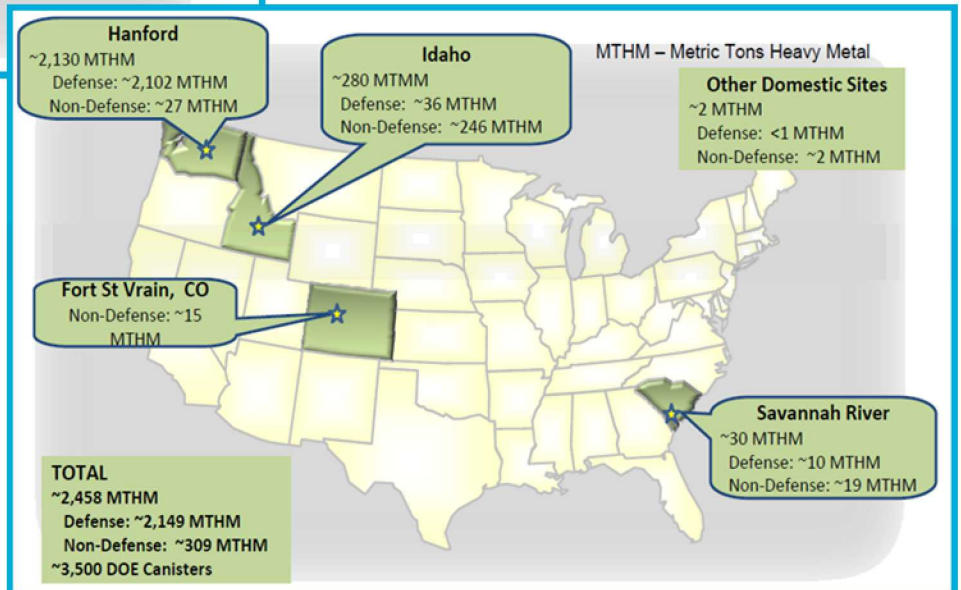


DOE-Managed  
HLW

~20,000 total  
canisters  
(projected)

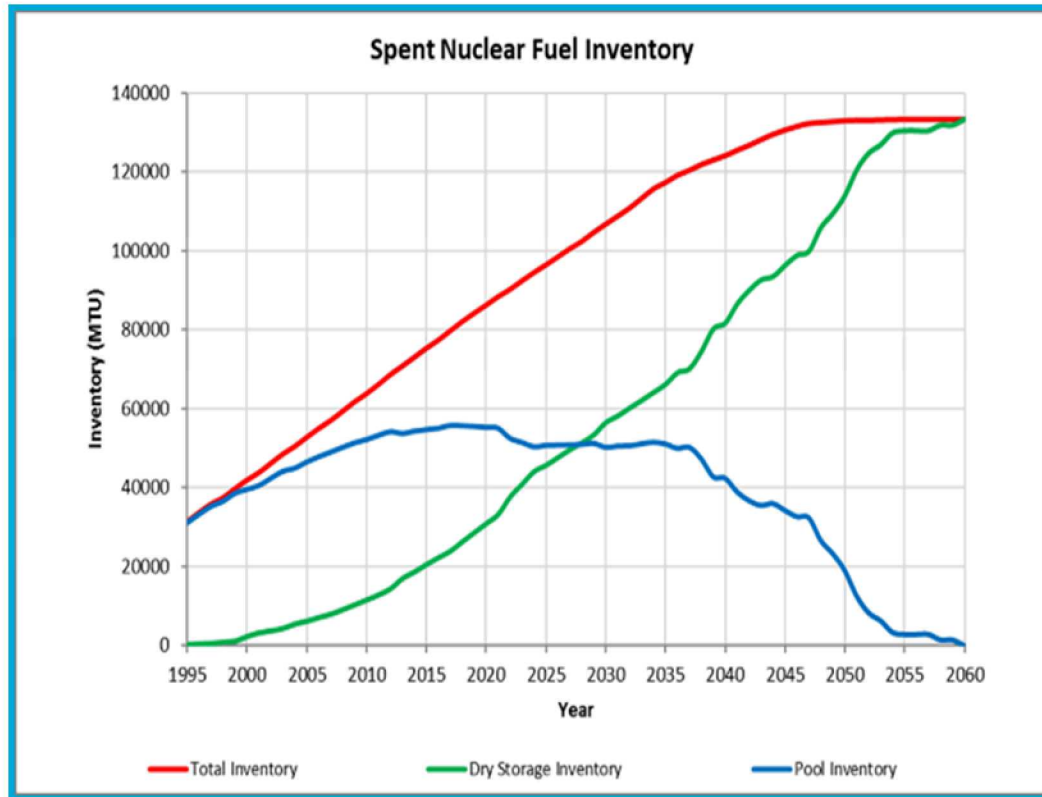


DOE-Managed SNF  
~2,458 Metric Tons



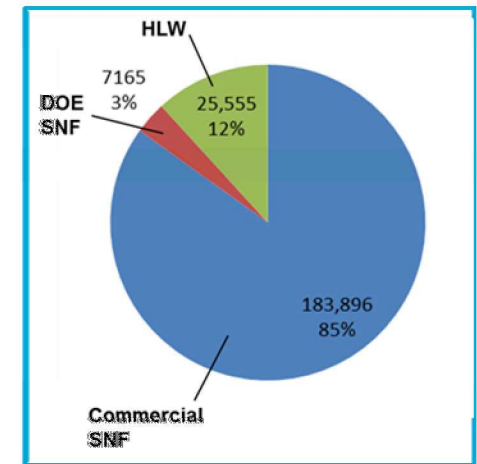
Source: Marcinowski, F., "Overview of DOE's Spent Nuclear Fuel and High-Level Waste," presentation to the Blue Ribbon Commission on America's Nuclear Future, March, 25, 2010, Washington, DC.

# US Projections of SNF and HLW



*Projection assumes full license renewals and no new reactor construction or disposal (Bonano et al., 2018)*

## Projected Volumes of SNF and HLW in 2048



*Volumes shown in m<sup>3</sup> assuming constant rate of nuclear power generation and packaging of future commercial SNF in existing designs of dual-purpose canisters.*

Approx. 77,000 MTHM (metric tons heavy metal) of commercial SNF in storage in the US as of Dec. 2016

Approx. 27,000 MTHM in dry storage at reactor sites, in approximately 2,700 cask/canister systems

- Balance in pools, mainly at reactors

Approx. 2200 MTHM of SNF generated nationwide each year

- Approximately 160 new dry storage canisters are loaded each year in the US

# Observations on Current Practice

- Current practice is safe and secure
  - Extending current practice raises data needs; e.g., canister integrity, fuel integrity, aging management practices
- Current practice is optimized for reactor site operations
  - Occupational dose
  - Operational efficiency of the reactor
  - Cost-effective on-site safety
- Current practice is not optimized for transportation or disposal
  - Thermal load, package size, and package design

**Placing spent fuel in dry storage in dual purpose canisters (DPCs) commits the US to some combination of three options**

- 1) Repackaging spent fuel in the future**
- 2) Constructing one or more repositories that can accommodate DPCs**
- 3) Storing spent fuel at surface facilities indefinitely, repackaging as needed**

**Each option is technically feasible, but none is what was originally planned**

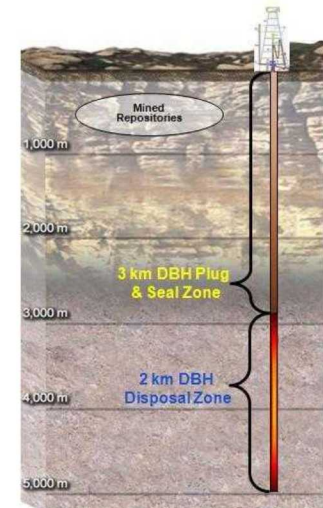
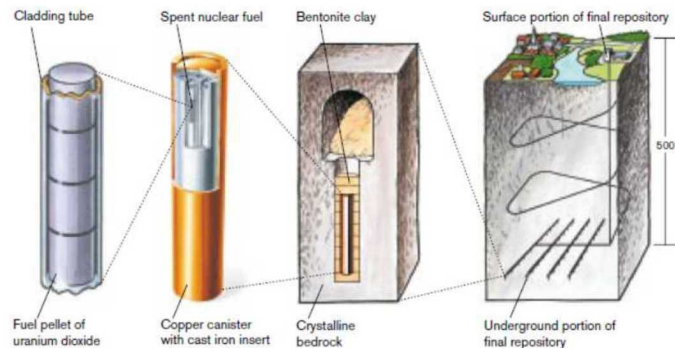
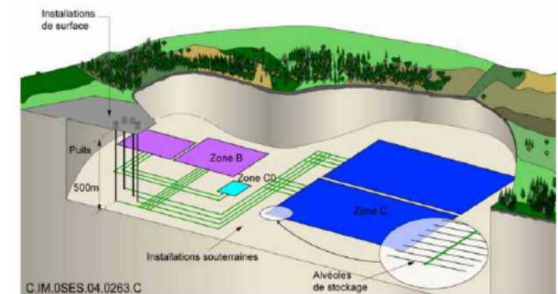
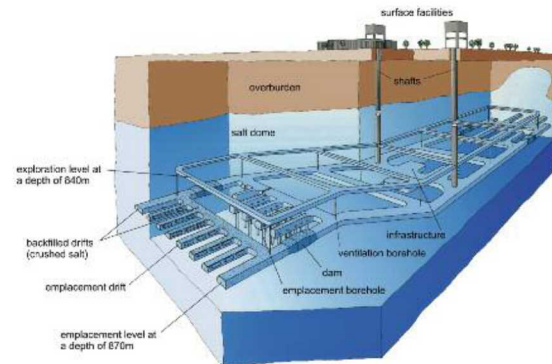
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*Deep geologic disposal has been planned since the 1950s*



# After Decades of Repository Science and Engineering, What Do We Have?

- Repository programs in multiple nations  
Belgium, Canada, China, Czech Republic, Finland, France, Germany, Japan, Korea, Russia, Spain, Sweden, Switzerland, United Kingdom, United States ...
- Detailed safety assessments have been published for multiple disposal concepts, e.g.,
  - Switzerland: Opalinus Clay, 2002
  - France; Dossier 2005 Argile, 2005
  - USA: Yucca Mountain License Application for a repository in tuff, 2008
  - Sweden: Forsmark site in granite, 2011
  - Finland: Safety Case for Olkiluoto site in gneiss, 2012
- One deep mined repository has been in operation for transuranic waste (the Waste Isolation Pilot Plant in the US) since 1999

## First order conclusions about geologic disposal

- There are multiple approaches to achieving safe geologic isolation
- Estimated long-term doses are very low for each of the disposal concepts that have been analyzed in detail
- Safe isolation can be achieved for both SNF and HLW

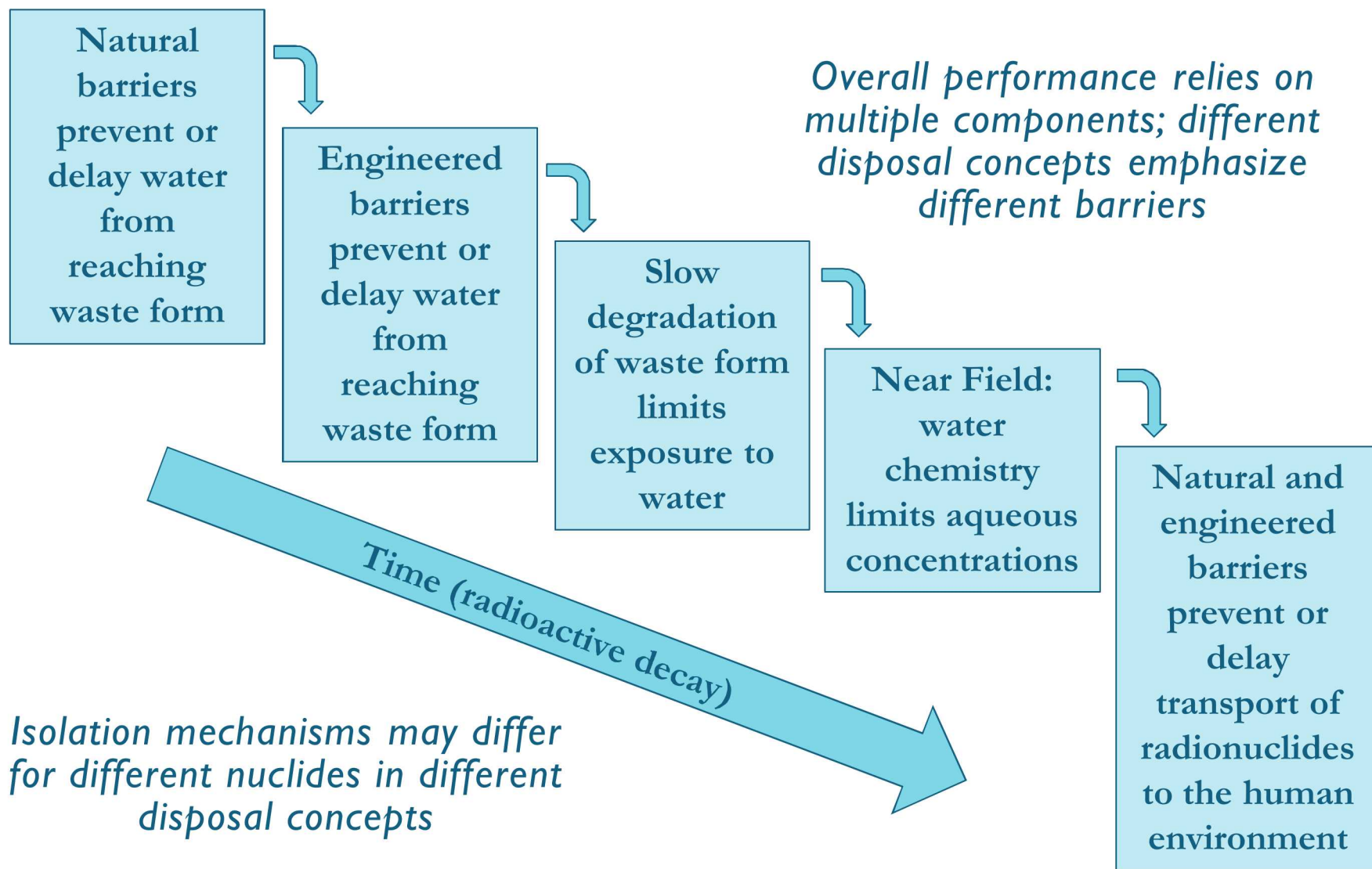
# Status of Deep Geologic Disposal Programs World-Wide

Nation	Host Rock	Status
Finland	Granitic Gneiss	Construction license granted 2015. Operations application to be submitted in 2020
Sweden	Granite	License application submitted 2011
France	Argillite	Disposal operations planned for 2025
Canada	Granite, sedimentary rock	Candidate sites being identified
China	Granite	Repository proposed in 2050
Russia	Granite, gneiss	Licensing planned for 2029
Germany	Salt, other	Uncertain
USA	Salt (transuranic waste at the Waste Isolation Pilot Plant) Volcanic Tuff (Yucca Mountain)	WIPP: operating Yucca Mountain: suspended

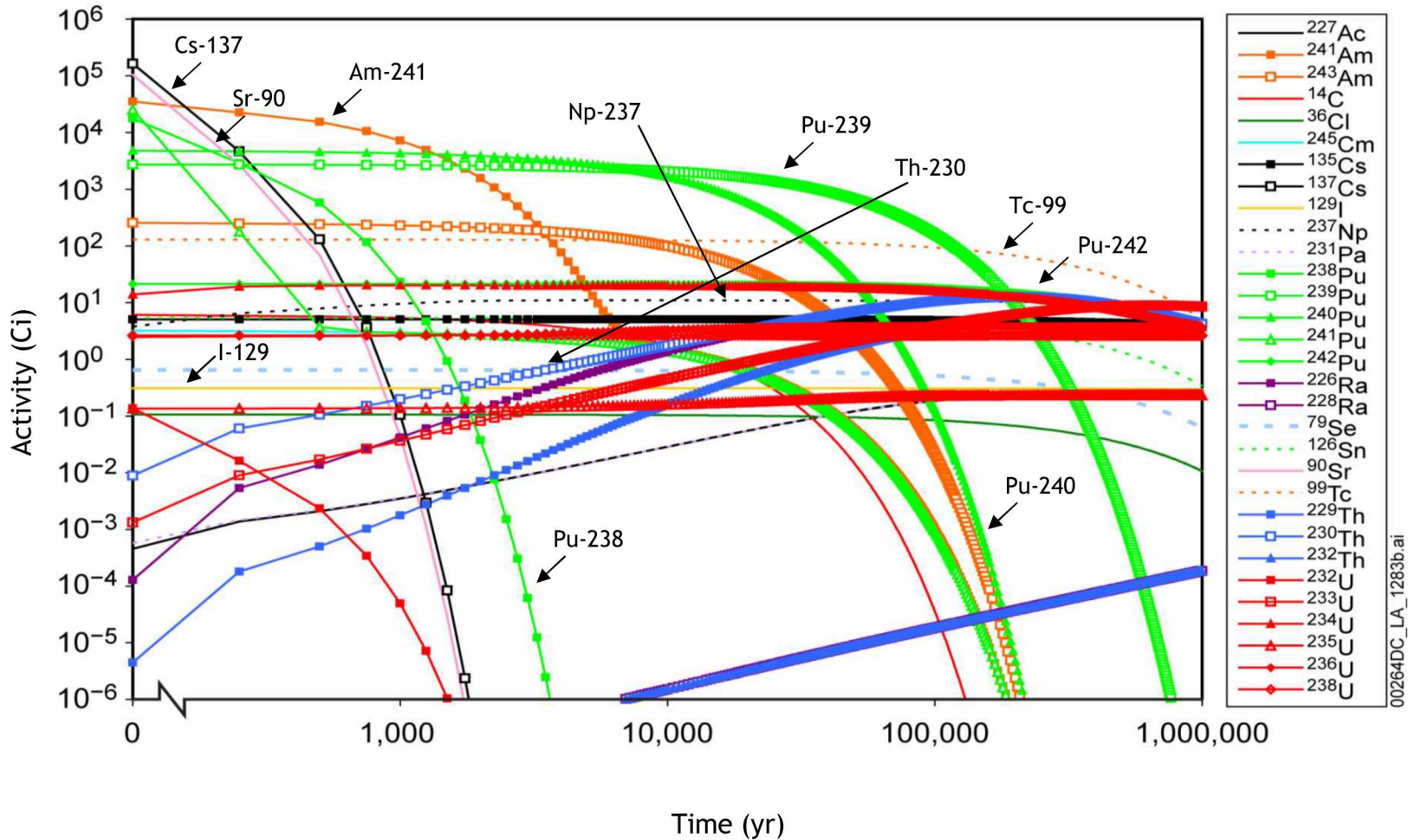
Others: Belgium (clay), Korea (granite), Japan (sedimentary rock, granite), UK (uncertain), Spain (uncertain), Switzerland (clay), Czech Republic (granitic rock), all nations with nuclear power.

Source: Information from Faybishenko et al., 2016

# How Repositories Work

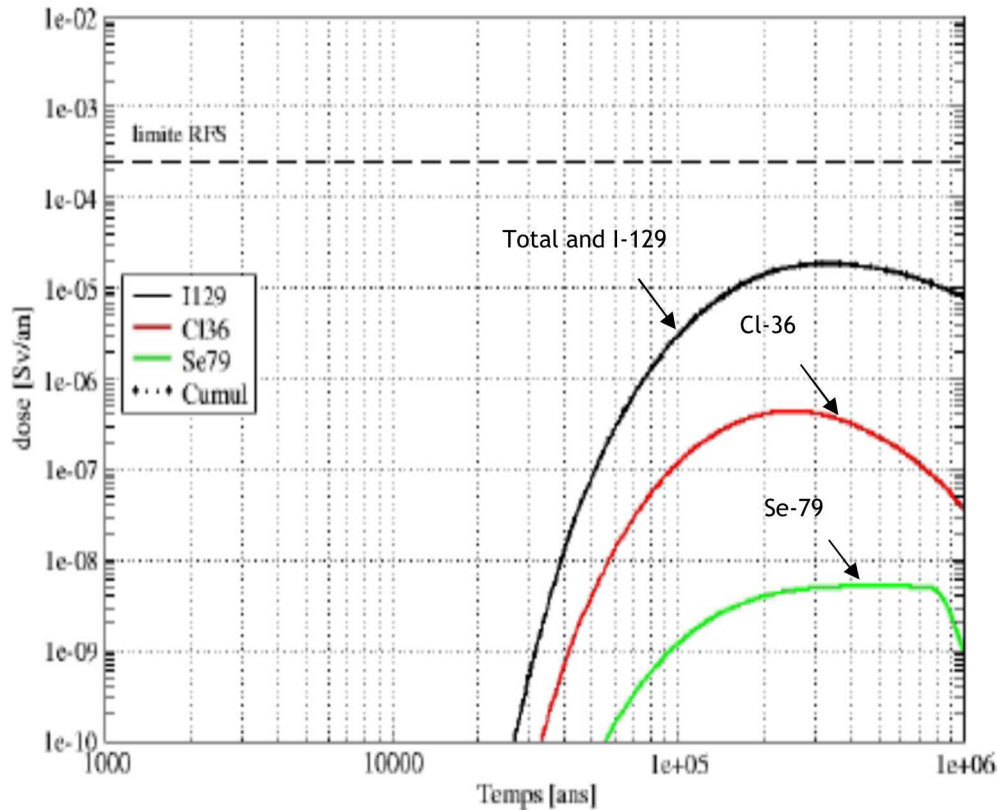


# Commercial Spent Nuclear Fuel Decay



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

# Contributors to Total Dose: Meuse / Haute Marne Site (France)

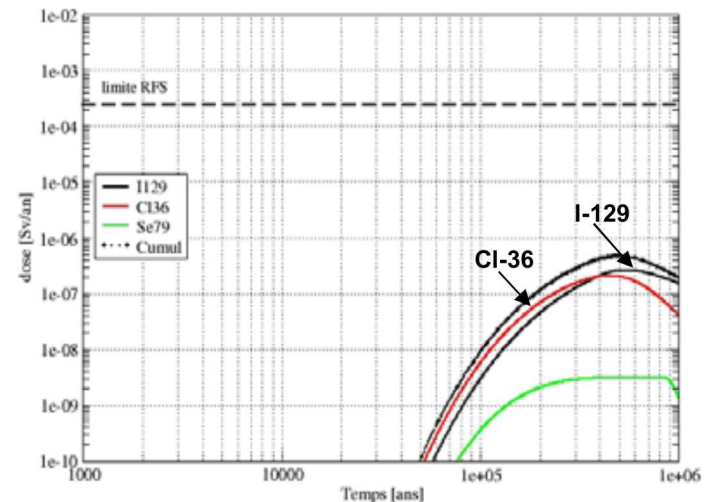


ANDRA 2005, *Dossier 2005: Argile. Tome: Evaluation of the Feasibility of a Geological Repository in an Argillaceous Formation*, Figure 5.5-18, SEN million year model, CU1 spent nuclear fuel and Figure 5.5-22, SEN million year model, C1+C2 vitrified waste

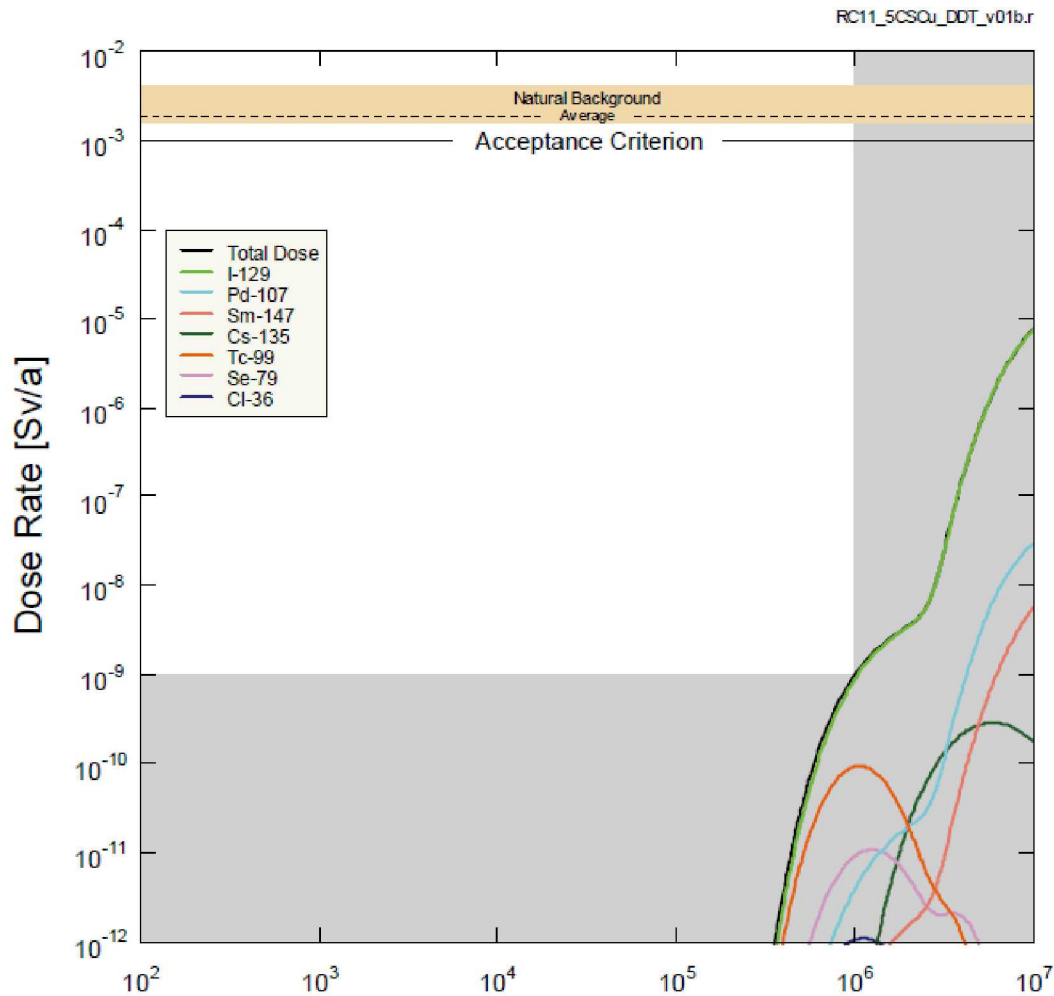
Diffusion-dominated disposal concept: Argillite

*I-129 is the dominant contributor at peak dose*

*Examples shown for direct disposal of spent fuel (left) and vitrified waste (below)*



# Contributors to Total Dose: Hypothetical site (Canada)



NWMO 2013, Adaptive Phased Management: Postclosure Safety Assessment of a Used Fuel Repository in Sedimentary Rock, NWMO TR-2013-07, Figure 7-96.

Diffusion-dominated disposal concept: spent fuel disposal in unfractured carbonate host rock

Long-lived copper waste packages and long diffusive transport path

All waste packages assumed to fail at 60,000 years for this simulation; primary barriers are slow dissolution of SNF and long diffusion paths

Major contributor to peak dose is I-129

# Contributors to Total Dose: Forsmark site (Sweden)

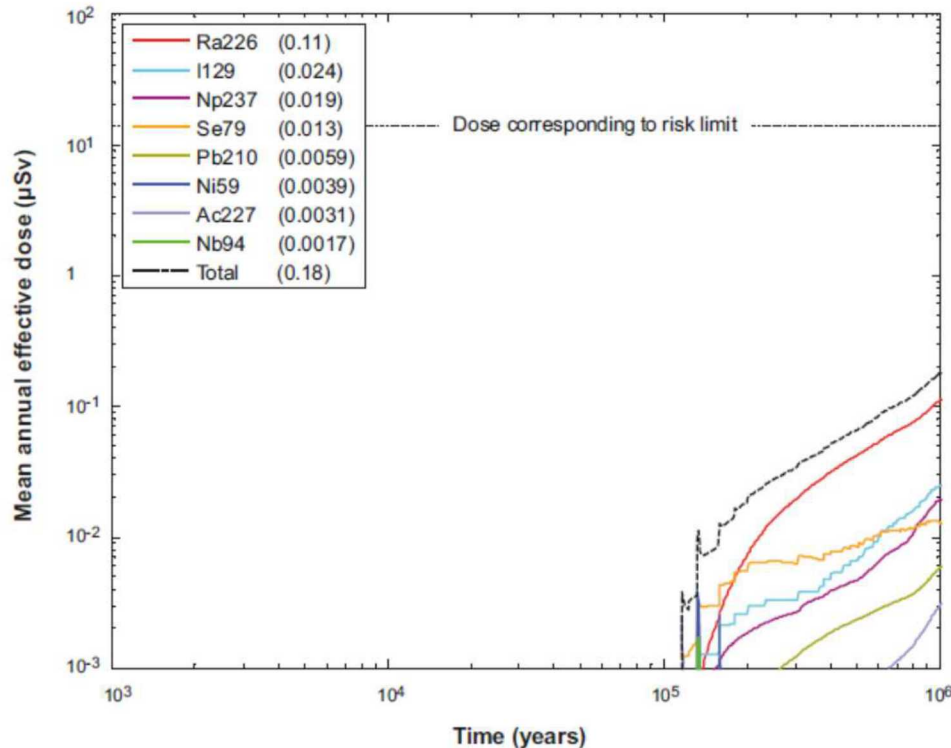


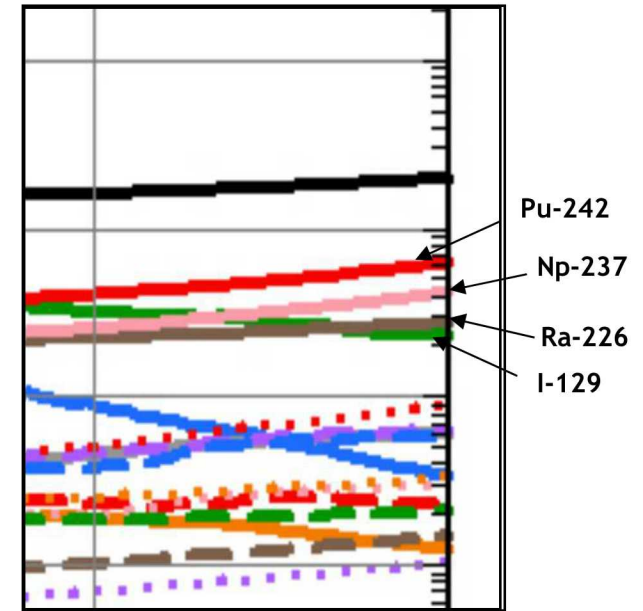
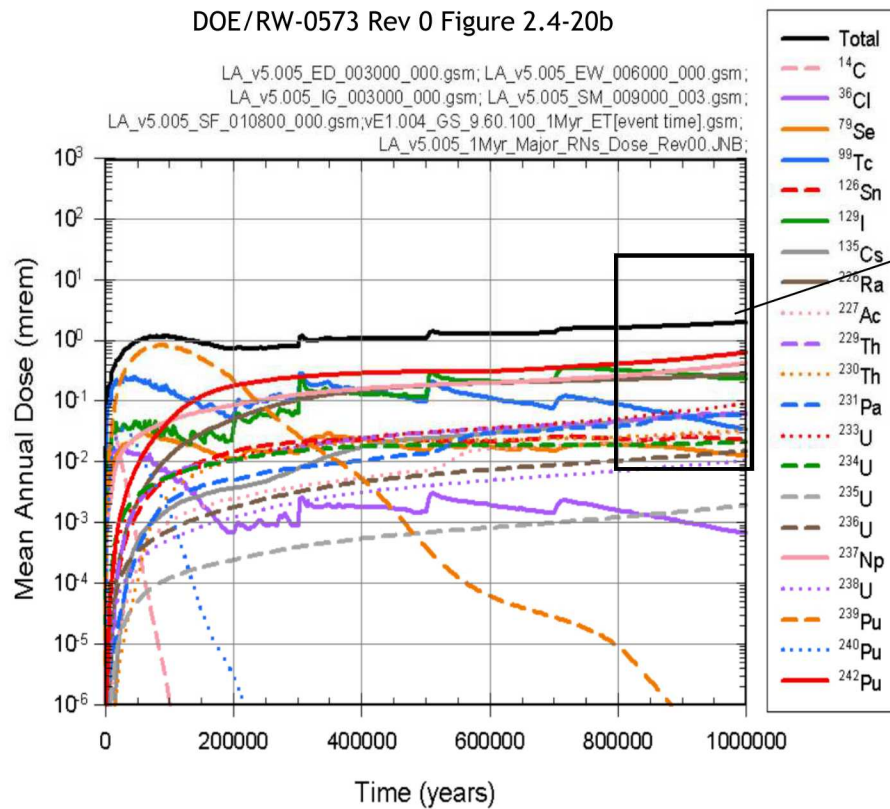
Figure 13-18. Far-field mean annual effective dose for the same case as in Figure 13-17. The legends are sorted according to descending peak mean annual effective dose over one million years (given in brackets in  $\mu\text{Sv}$ ).

SKB 2011, Long-term safety for the final repository for spent nuclear fuel at Forsmark, Technical Report TR-11-01

Disposal concept with advective transport in the far-field: Fractured Granite

*Long-term peak dose dominated by Ra-226  
Once corrosion failure occurs, dose is primarily controlled by fuel dissolution and diffusion through buffer rather than far-field retardation*

# Contributors to Total Dose: Yucca Mountain (USA)



Disposal concept with an oxidizing environment and advective transport in the far-field: Fractured Tuff

*Actinides are significant contributors to dose; I-129 is approx. 1/10<sup>th</sup> of total*

# Conclusions

Deep geologic disposal remains the preferred approach for permanent isolation of SNF and HLW

Interim storage of commercial SNF occurs in the US at all operating reactor sites

- The existing inventory of SNF exceeds the legal capacity of the proposed Yucca Mountain repository
- Interim storage will continue for decades longer than originally envisioned

Interim storage of DOE-managed SNF and HLW in the US continues at multiple sites

Multiple geologic disposal options are technically feasible, including the proposed site at Yucca Mountain, Nevada

- Different disposal concepts rely on different combinations of engineered and natural barriers to achieve isolation

ANDRA (Agence nationale pour la gestion des déchets radioactifs), 2005. Dossier 2005: Argile. Tome: Safety Evaluation of a Geological Repository (English translation: original documentation written in French remains ultimately the reference documentation).

Bonano, E., Kalinina, E., and Swift, P., 2018, The Need for Integrating the Back End of the Nuclear Fuel Cycle in the United States of America. MRS Advances, 1-13. doi:10.1557/adv.2018.231

Faybishenko, B., Birkholzer, J., Sassani, D., and Swift, P., 2016. International Approaches for Deep Geological Disposal of Nuclear Waste: Geological Challenges in Radioactive Waste Isolation, Fifth Worldwide Review, LBNL-1006984, Lawrence Berkeley National Laboratory.

NAGRA (Nationale Genossenschaft für die Lagerung Radioactiver Abfälle [National Cooperative for the Disposal of Radioactive Waste]), 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.

National Research Council / National Academies, 2001. Disposition of High-Level Waste and Spent Nuclear Fuel: The Continuing Societal and Technical Challenges, Washington, DC, National Academy Press.

NWMO (Nuclear Waste Management Organization), 2013. Adaptive Phased Management: Postclosure Safety Assessment of a Used Fuel Repository in Sedimentary Rock, NWMO TR-2013-07.

Posiva Oy, 2012, Safety Case for the Disposal of Spent Nuclear Fuel at Olkiluoto—Synthesis 2012, POSIVA 2012-12.

SKB (Svensk Kämbränslehantering AB [Swedish Nuclear Fuel and Waste Management Co.]), 2011. Long-Term Safety for the Final Repository for Spent Nuclear Fuel at Forsmark: Main Report of the SR-Site Project, Technical Report TR-11-01.

Swift, P.N., and W.M. Nutt, 2010. “Applying Insights from Repository Safety Assessments to Evaluating Impacts of Partitioning and Transmutation,” Proceedings of the 11th OECD-NEA Information Exchange Meeting on Actinide and Fission Product Partitioning and Transmutation, San Francisco, CA, November 1-4, 2010.

US DOE (United States Department of Energy) 2008. Yucca Mountain Repository License Application, DOE/RW-0573, Rev. 1.