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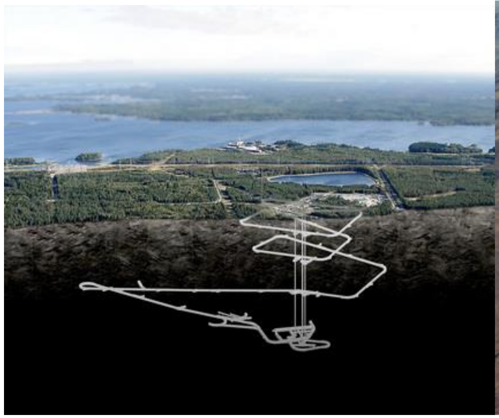

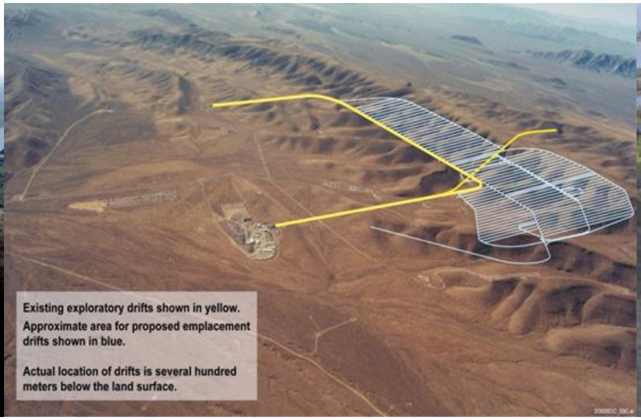

Recent Developments in Disposal of High-Level Radioactive Waste and Spent Nuclear Fuel

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Sandia National Laboratories

Interagency Steering Committee on Performance and Risk Assessment Community of Practice
Annual Technical Exchange Meeting
Albuquerque NM
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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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Outline

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

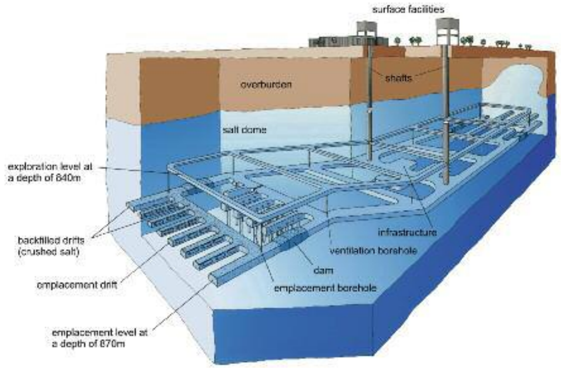
Spent Nuclear Fuel and High-Level Radioactive Waste Disposal: The Goal

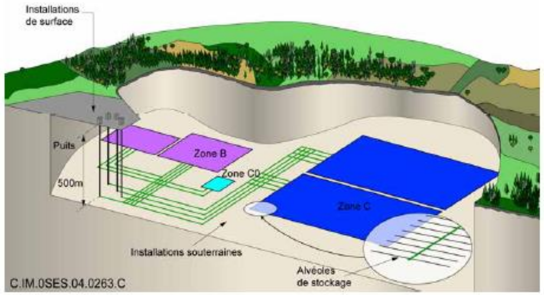
Deep geologic disposal has been planned since the 1950s

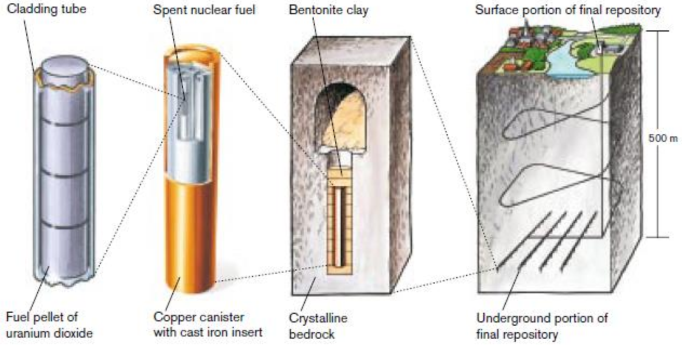
"There has been, for decades, a worldwide consensus in the nuclear technical community for disposal through geological isolation of high-level waste (HLW), including spent nuclear fuel (SNF)."

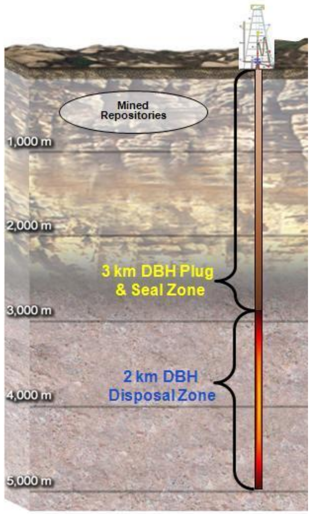
"Geological disposal remains the only long-term solution available."

National Research Council, 2001





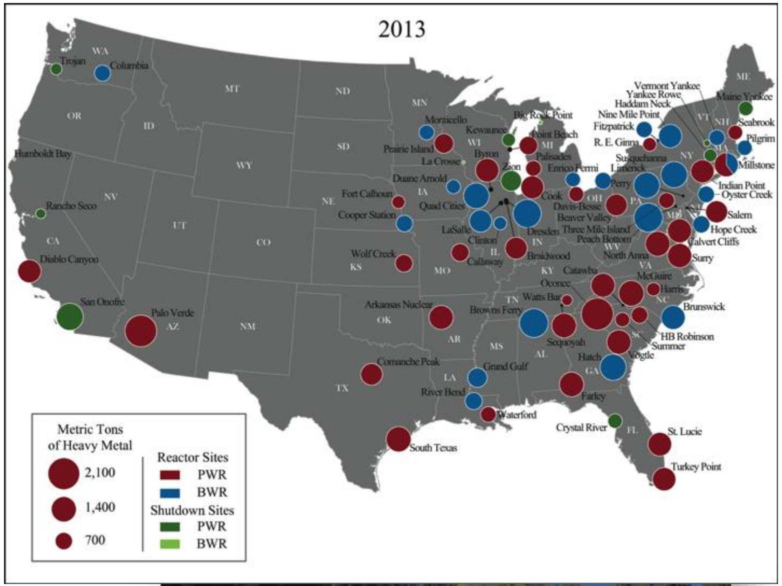


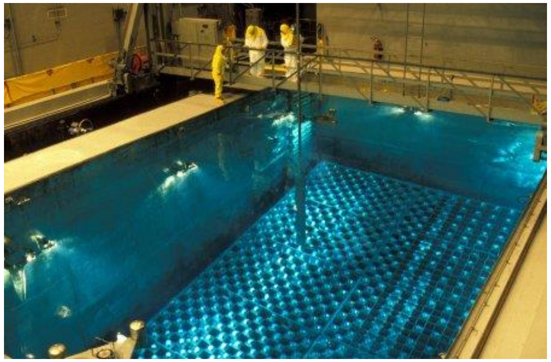


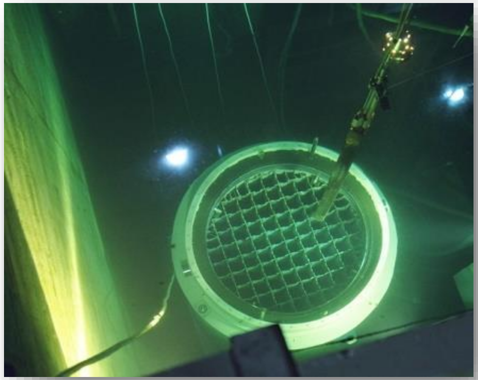
Geologic Disposal in the US: The Reality

Commercial Spent Nuclear Fuel (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 installation (ISFSI)







Geologic Disposal in the US: The Reality

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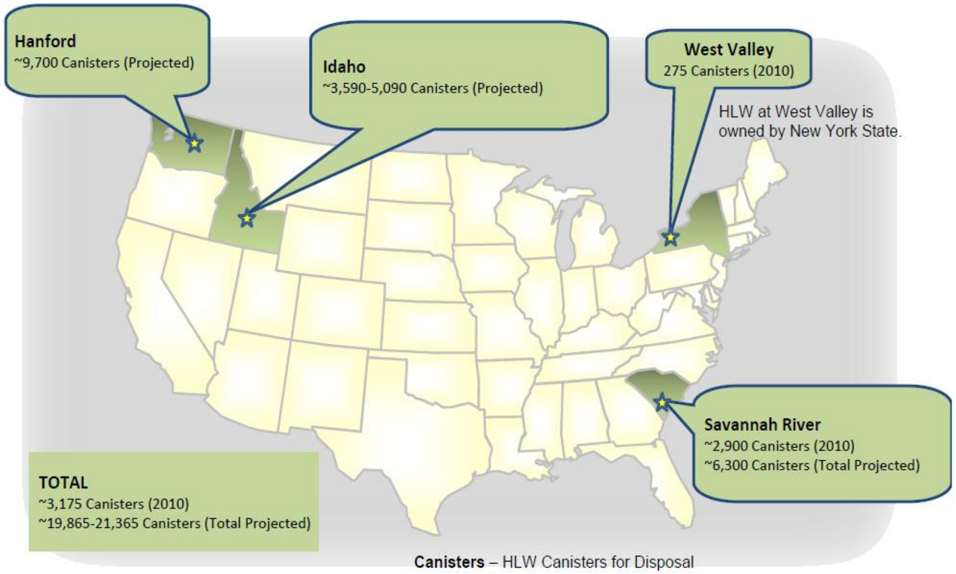
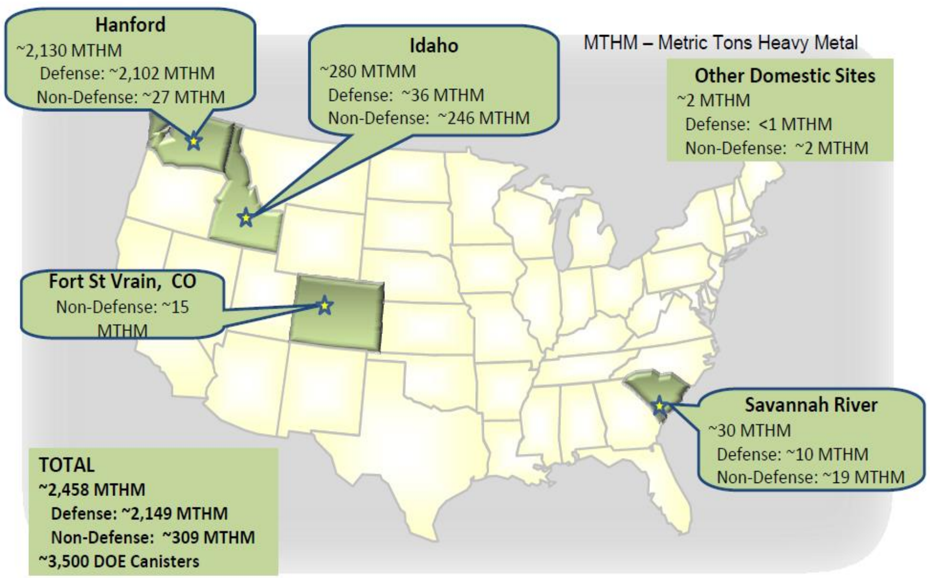
DOE-managed SNF and High-Level Radioactive Waste (HLW) is in Temporary Storage at 5 Sites in 5 States



DOE-Managed HLW
~20,000 total canisters
(projected)

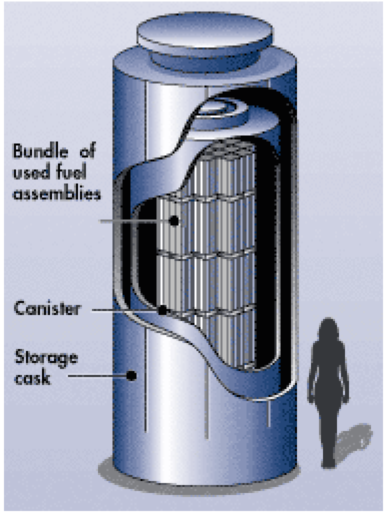
DOE-Managed SNF
~2,458 Metric Tons



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.

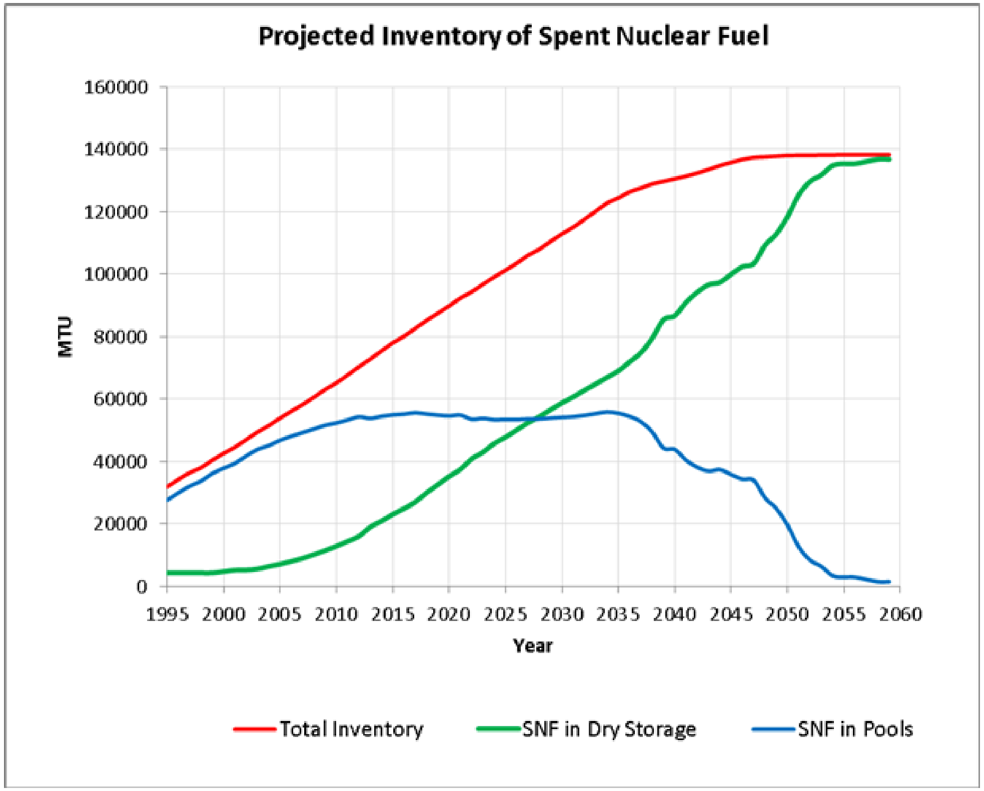
Dry Storage Systems for Spent Nuclear Fuel

- Dual purpose canister (DPC)
  - A canister that is certified for both storage and transportation of spent nuclear fuel
- Dry cask/canister storage systems
  - The most common type of dry storage cask system is the vertical cask/canister system shown above, in which the inner stainless steel canister is removed from the storage overpack before being placed in a shielded transportation cask for transport
    - Can be constructed both above and below grade
  - Horizontal bunker-type systems and vaults are also in use
- Some older fuel is also stored as "bare fuel" in casks with bolted lids; few sites continue to load these systems
- Multiple vendors provide NRC-certified dry storage systems to utilities

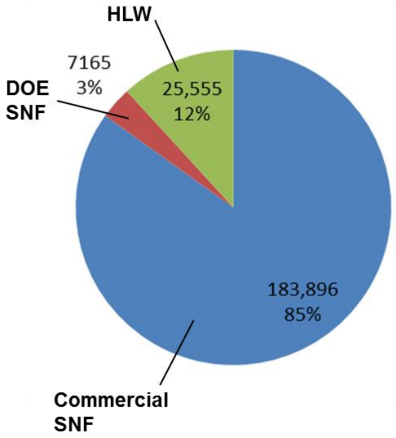


US Projections of Spent Nuclear Fuel (SNF) and High-Level Radioactive Waste (HLW)

Projection assumes full license renewals and no new reactor construction or disposal



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

Approx. 80,150 MTHM (metric tons heavy metal) of SNF in storage in the US today
- 25,400 MTHM in dry storage at reactor sites, in approximately 2,080 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

Current Storage and Transportation R&D

Spent fuel integrity

- Current tests and analyses indicate that spent fuel is more robust than was previously thought
- The *DOE/EPRI High Burnup Confirmatory Data Project* will obtain data after 10 years of dry storage to confirm current test and analysis results from parallel hot cell testing of “sister rods”

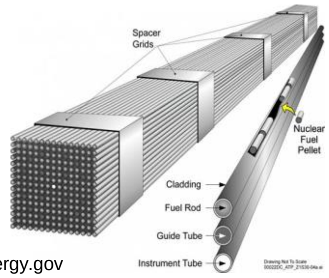


Photo: energy.gov

Storage system integrity

- *Stress corrosion cracking of canisters may be a concern in some parts of the country, and more work is needed in analysis and detection*
- *Monitoring and Aging Management practices at storage sites will be important to confirm storage system performance during extended service*

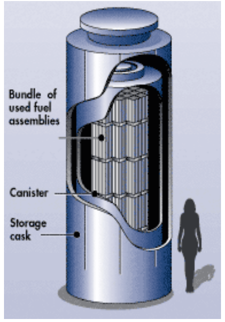
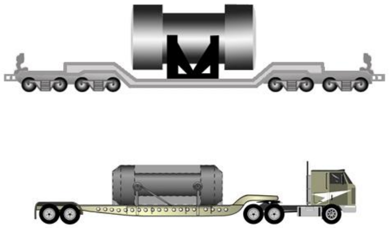


Photo: nrc.gov

Spent fuel transportability following extended storage

- *The realistic stresses fuel experiences due to vibration and shock during normal transportation are far below yield and fatigue limits for cladding*


Energy.gov/pictures

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

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

Deep geologic disposal has been planned since the 1950s

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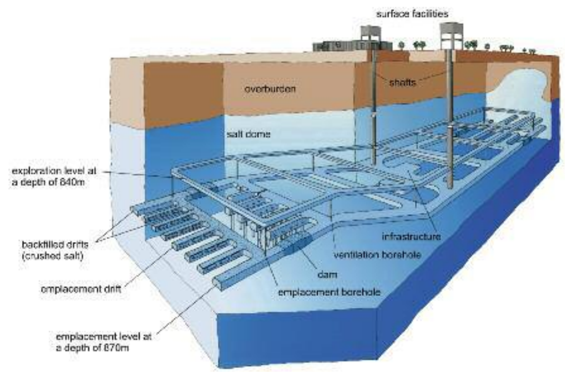
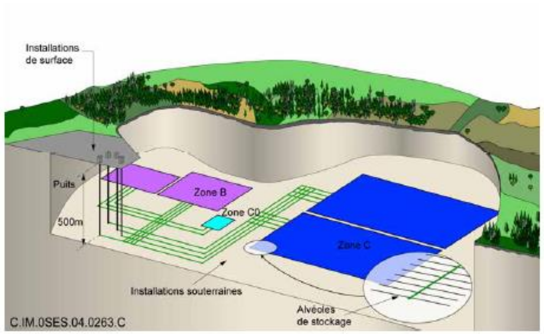
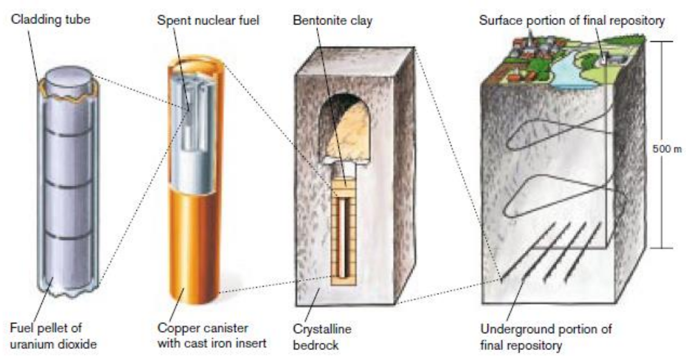
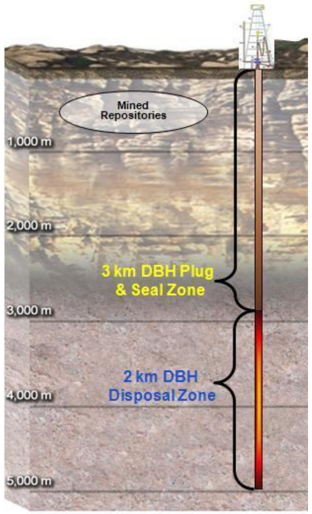








After Decades of Repository Science and Engineering, What do We Have?

- 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, 2008
  - Sweden: Forsmark site in granite, 2011
  - Finland: Safety Case for Olkiluoto, 2012
- One deep mined repository has been in operation for transuranic waste (the Waste Isolation Pilot Plant) since 1999

First order conclusions

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 spent nuclear fuel and HLW

Status of Deep Geologic Disposal Programs World-Wide

Nation	Host Rock	Status
Finland	Granitic Gneiss	Construction license granted 2015
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), others including all nations with nuclear power. Source: Information from Faybishenko et al., 2016		

How does Deep Geologic Disposal Achieve Safe Isolation?

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

Natural barriers prevent or delay water from reaching waste form

Engineered barriers prevent or delay water from reaching waste form

Slow degradation of waste form limits exposure to water

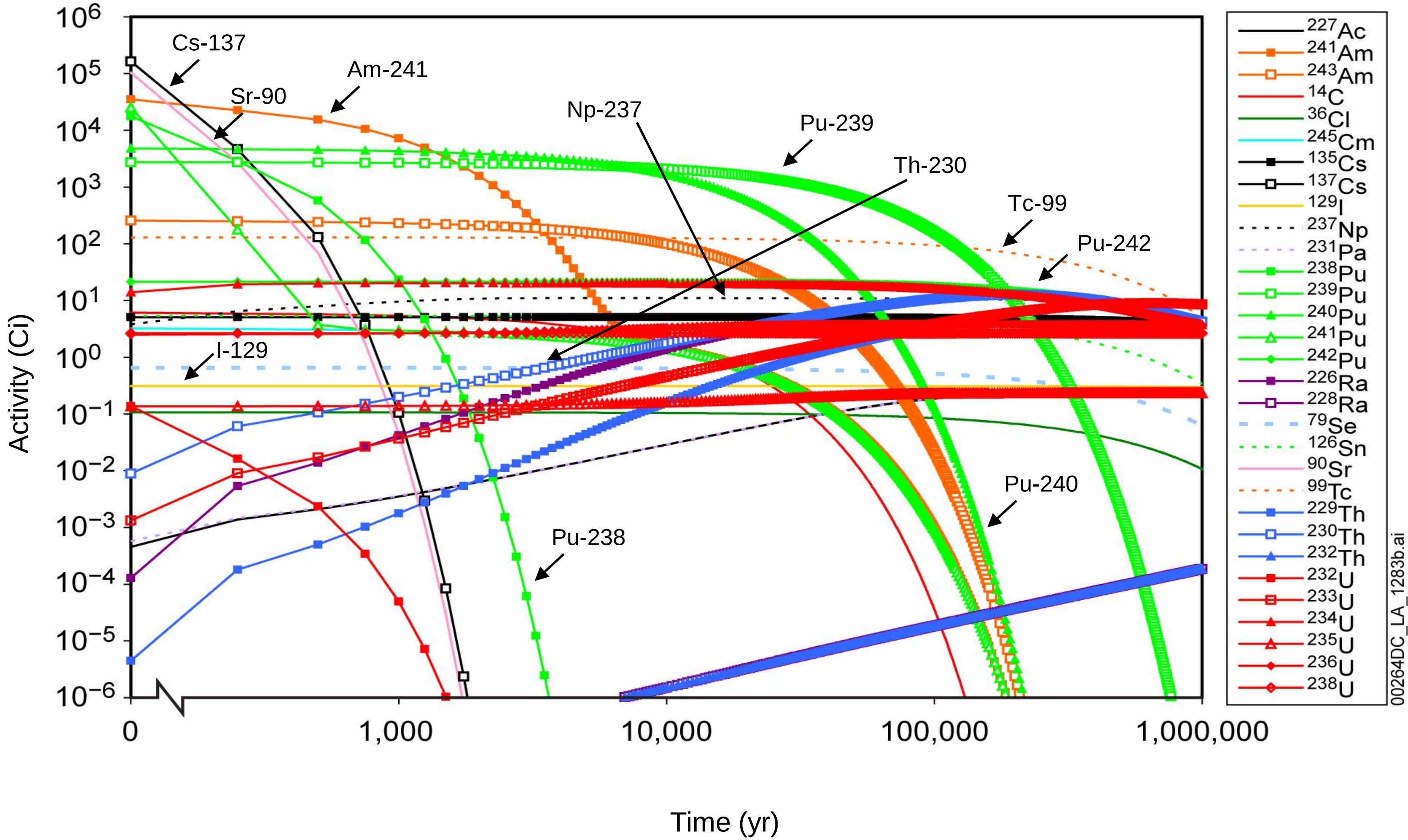
Near Field: water chemistry limits aqueous concentrations

Natural and engineered barriers prevent or delay transport of radionuclides to the human environment

Time (radioactive decay)

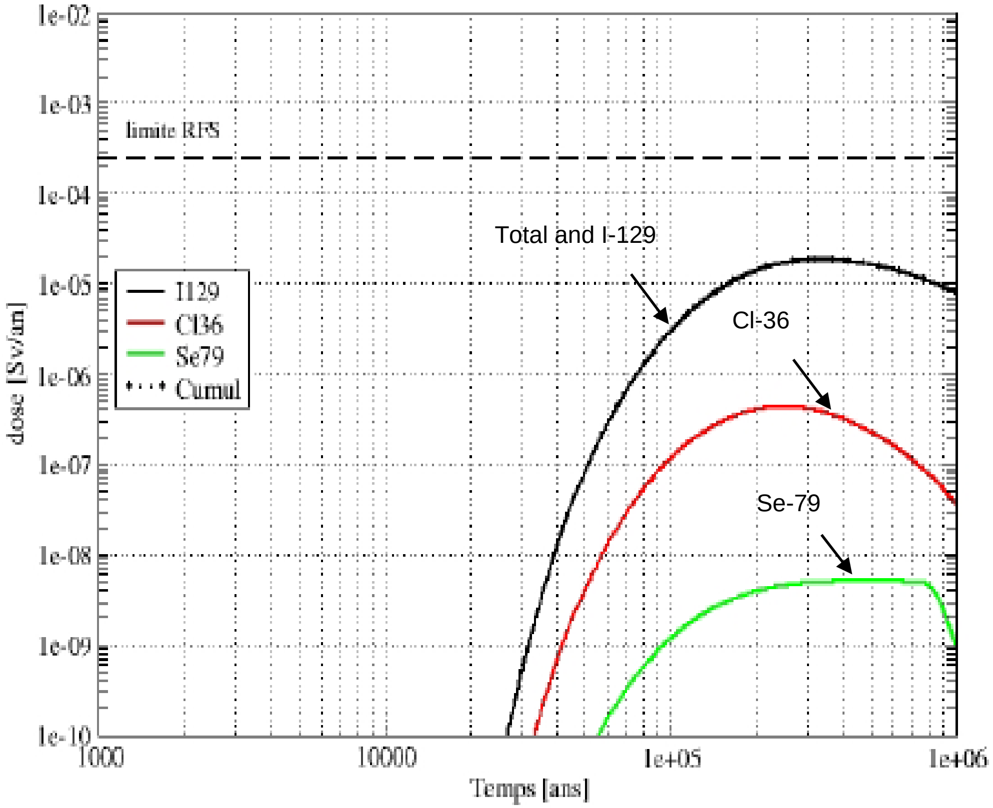
Isolation mechanisms may differ for different nuclides in different disposal concepts

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)

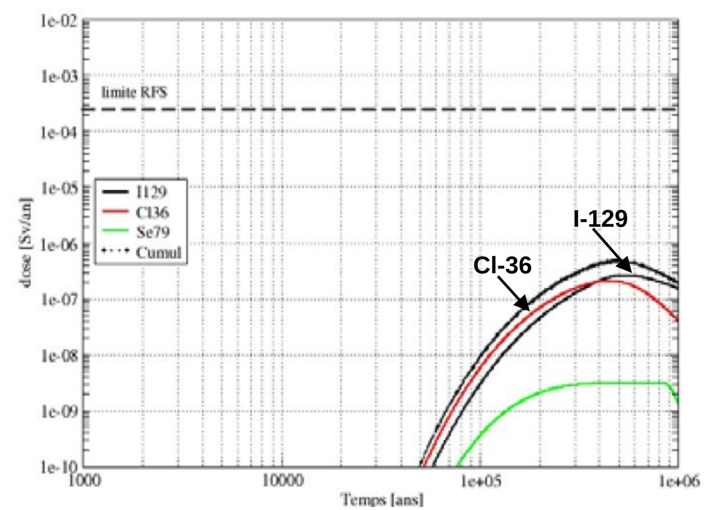


ANDRA 2005, *Dossier 2005: Argile. Tome: Evaluation of the Feasibility of a Geological Repository in an Argillaceous Formation*, Figure 5.5-18, SEN million year model, CU1 spent nuclear fuel and Figure 5.5-22, SEN million year model, C1+C2 vitrified waste

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: Forsmark site (Sweden)

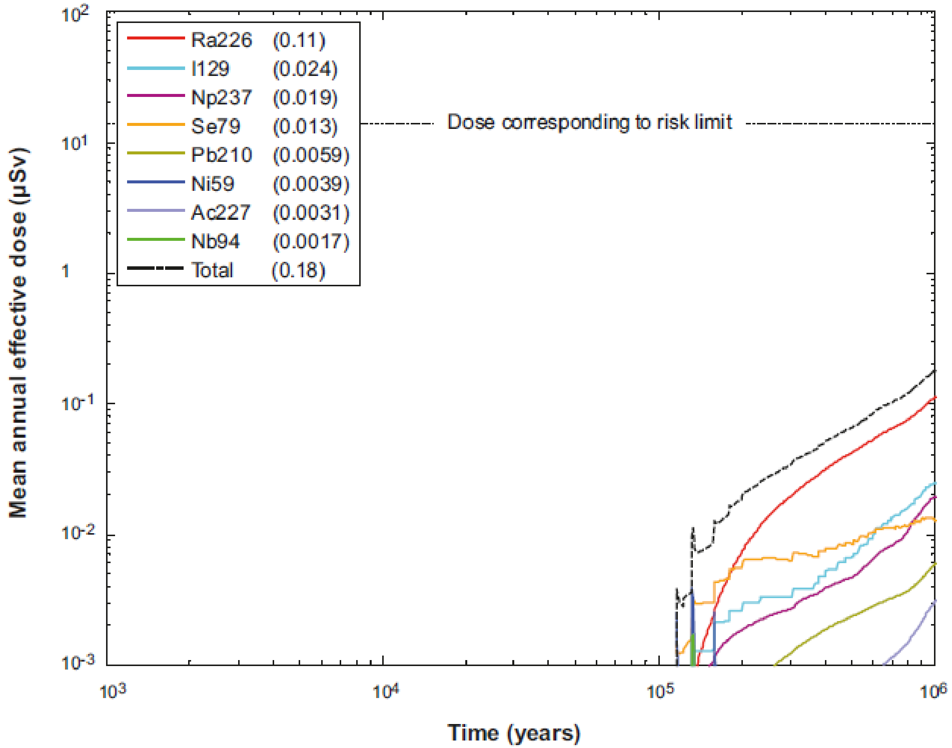


***Figure 13-18.** Far-field mean annual effective dose for the same case as in Figure 13-17. The legends are sorted according to descending peak mean annual effective dose over one million years (given in brackets in µSv).*

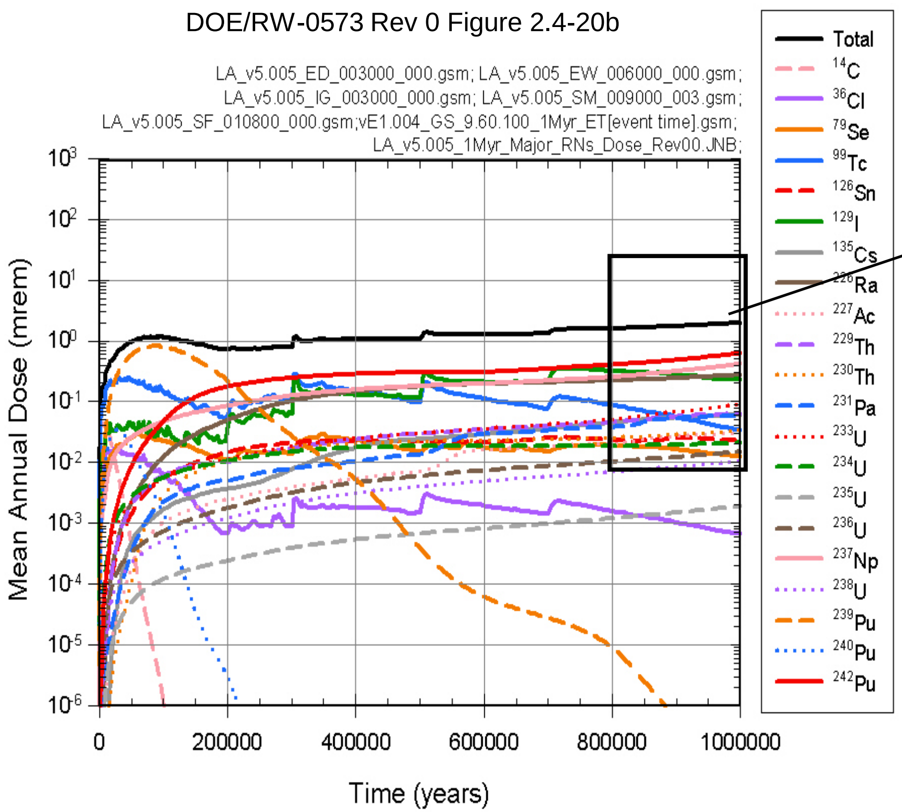
SKB 2011, Long-term safety for the final repository for spent nuclear fuel at Forsmark, Technical Report TR-11-01

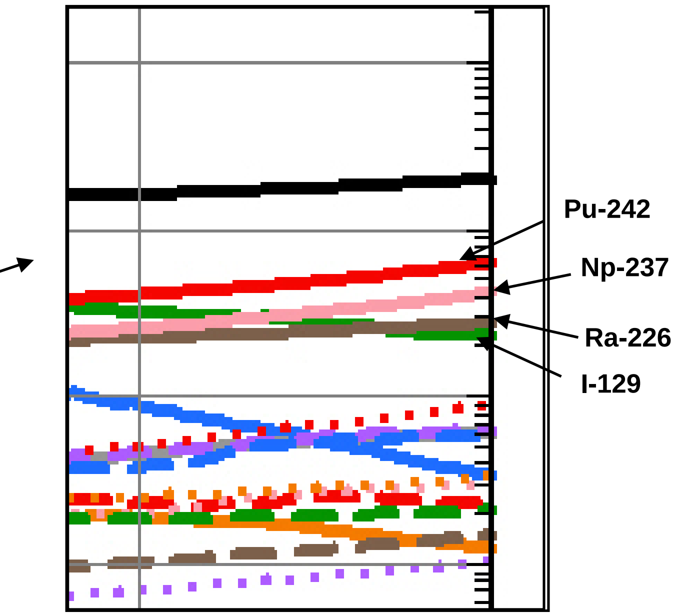
Disposal concept with advective transport in the far-field: Fractured Granite

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

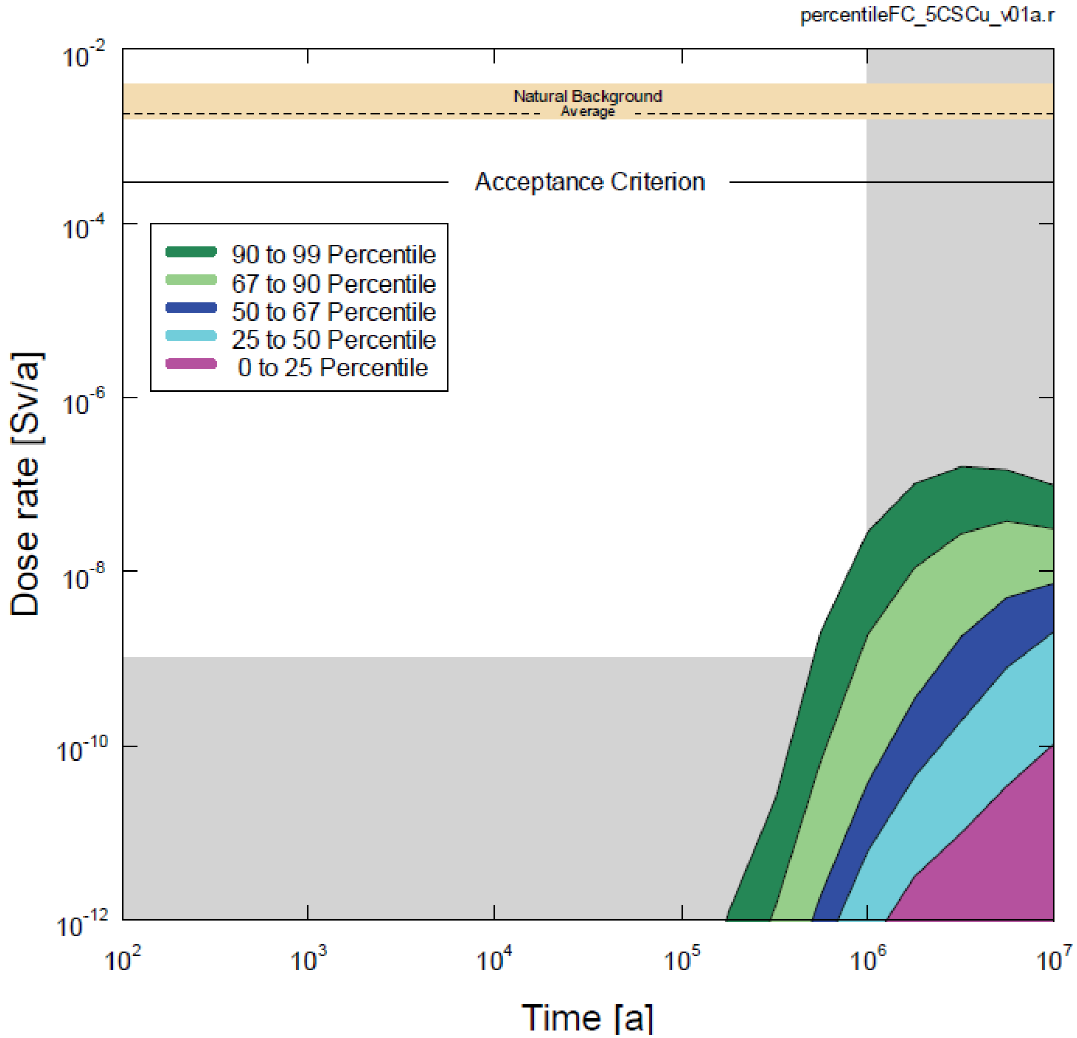




Disposal concept with an oxidizing environment and advective transport in the far-field: Fractured Tuff

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

Long-term Dose Estimates: Canada



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

Long-lived copper waste packages and long diffusive transport path

Major contributor to peak dose is I-129

NWMO 2013, Adaptive Phased Management: Postclosure Safety Assessment of a Used Fuel Repository in Sedimentary Rock, NWMO TR-2013-07, Figure 7-87.

Conclusions

- Deep geologic disposal remains the preferred approach for permanent isolation of SNF and HLW
- Interim storage of commercial SNF occurs 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 continues at multiple sites
- Multiple geologic disposal options are technically feasible, including the proposed site at Yucca Mountain, Nevada

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