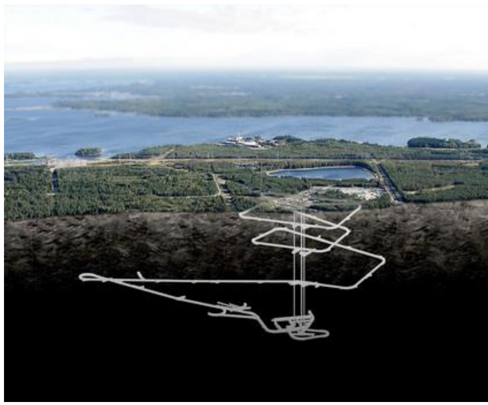

Deep Geologic Disposal of Radioactive Waste: Multiple Options for Long-Term Isolation

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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Progress in Deep Geologic Disposal

- Three examples out of many

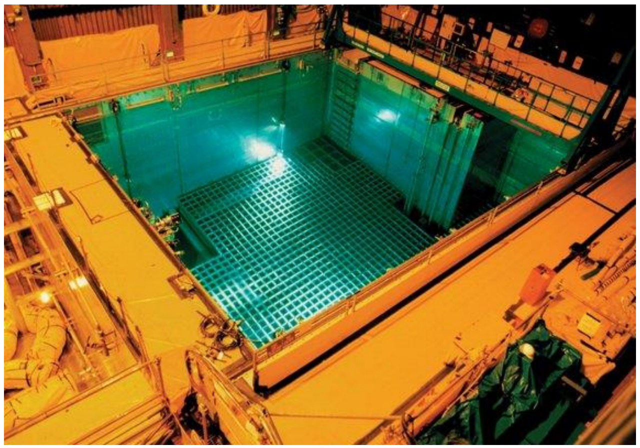
	2006 Plans	2016 Actions
Finland	Submit license application in 2012	License application submitted 28 December 2012 Construction License granted 12 November 2015
Sweden	Select a site by 2008	Forsmark site selected 3 June 2009 License application submitted 16 March 2011
Canada	Adaptive Phased Management recommended as an approach	More than 20 communities have expressed interest Eight areas currently being studied as potential candidates for further consideration

Current Status of the US Program

- **2008**: Yucca Mountain Repository License Application submitted
- **2009**: Department of Energy (DOE) determines Yucca Mountain to be unworkable
- **2010**: Last year of funding for Yucca Mountain project
- **2012**: Blue Ribbon Commission on America's Nuclear Future completes its recommendations, including a call for a consent-based process to identify alternative storage and disposal sites
- **2013**: Federal Court of Appeals orders Nuclear Regulatory Commission (NRC) to complete its staff review of the Yucca Mountain application with remaining funds
- **2014**: Transuranic waste disposal operations at the Waste Isolation Pilot Plant cease after an underground fire and radiological release
- **2015**: NRC staff completes Yucca Mountain review, finds that "the DOE has demonstrated compliance with the NRC regulatory requirements" for both preclosure and postclosure safety
- **2015**: DOE begins consideration of a separate repository for defense high-level wastes
- **2015**: DOE initiates first phase of public interactions planning for a consent-based siting process for both storage and disposal facilities
- **2016**: Yucca Mountain licensing process remains suspended, and approximately 300 technical contentions remain to be heard before a licensing board can reach a decision
- **2016**: Private sector applications to the NRC for consolidated interim storage (1 submitted, 1 anticipated)

What Comes Next in the US?

Surface storage of spent nuclear fuel will continue

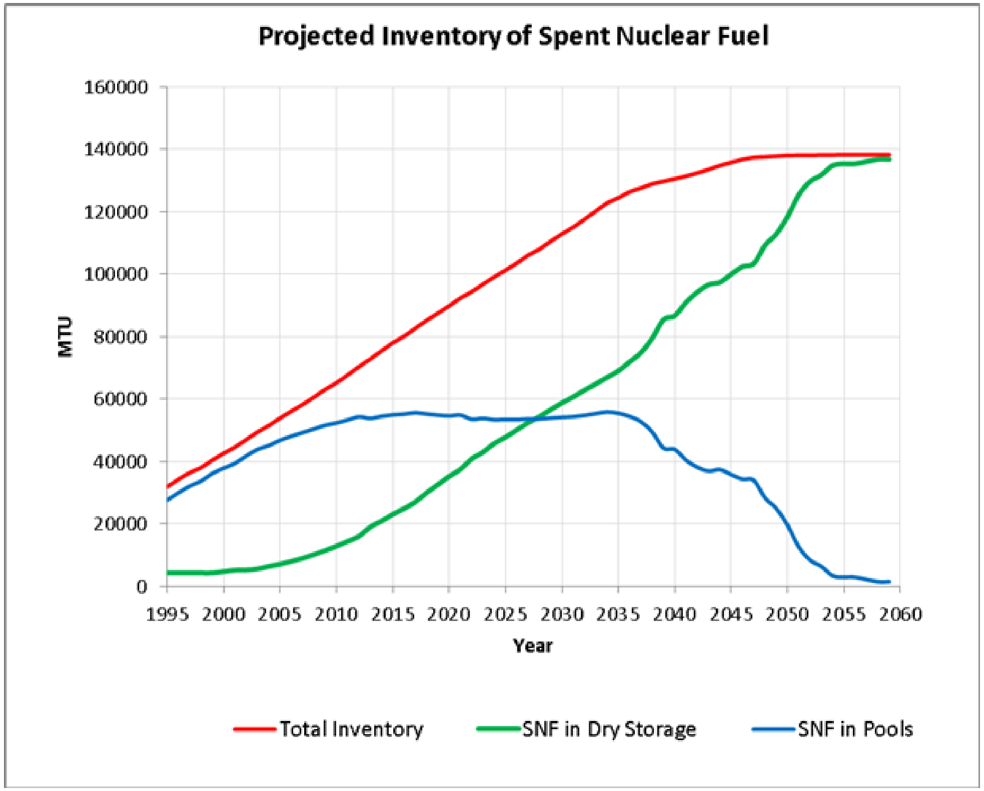


Pool Storage: essential to reactor operations, but nearing capacity, ~ 80% of existing US reactors have dry storage facilities on site

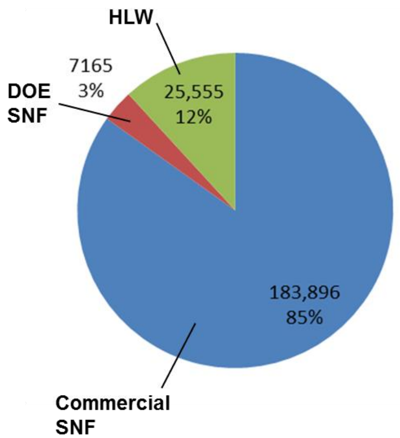
Dry Storage: horizontal and vertical concepts are in use. R&D in progress to support the technical basis for license extensions beyond original 20-yr period

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

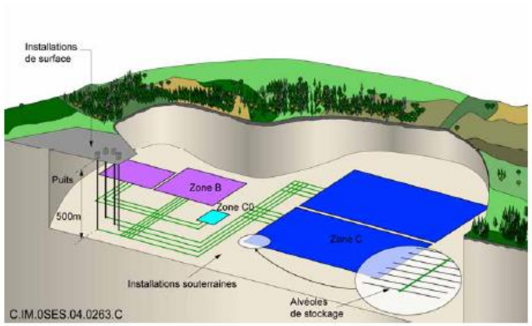
Approx. 2200 MTHM of SNF generated nationwide each year

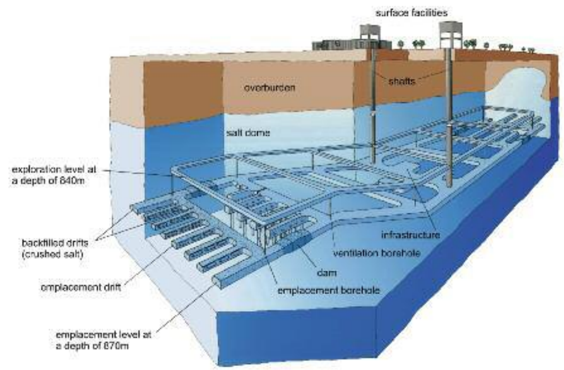
- Approximately 160 new dry storage canisters are loaded each year in the US

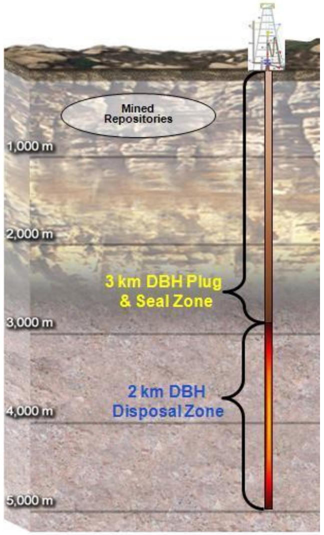
Deep Geologic Disposal Remains an Essential Element of Nuclear Waste Management

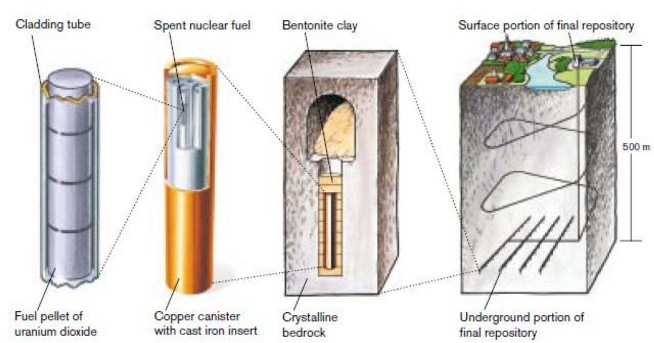
"The conclusion that disposal is needed and that deep geologic disposal is the scientifically preferred approach has been reached by every expert panel that has looked at the issue and by every other country that is pursuing a nuclear waste management program."

Blue Ribbon Commission on America's Nuclear Future, 2012









How do Repositories 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

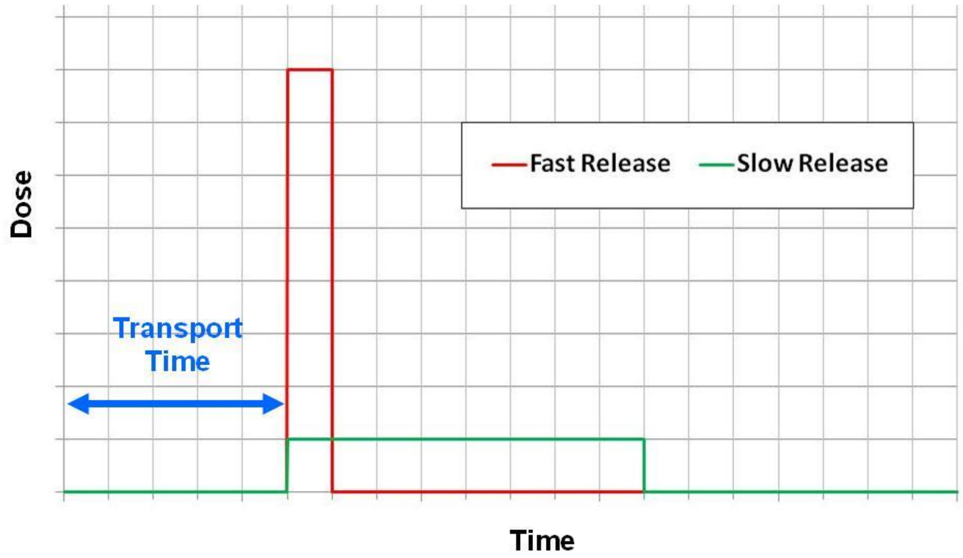
Time (radioactive decay)

Isolation mechanisms may differ for different nuclides in different disposal concepts

Simplistic Insights from Safety Assessments

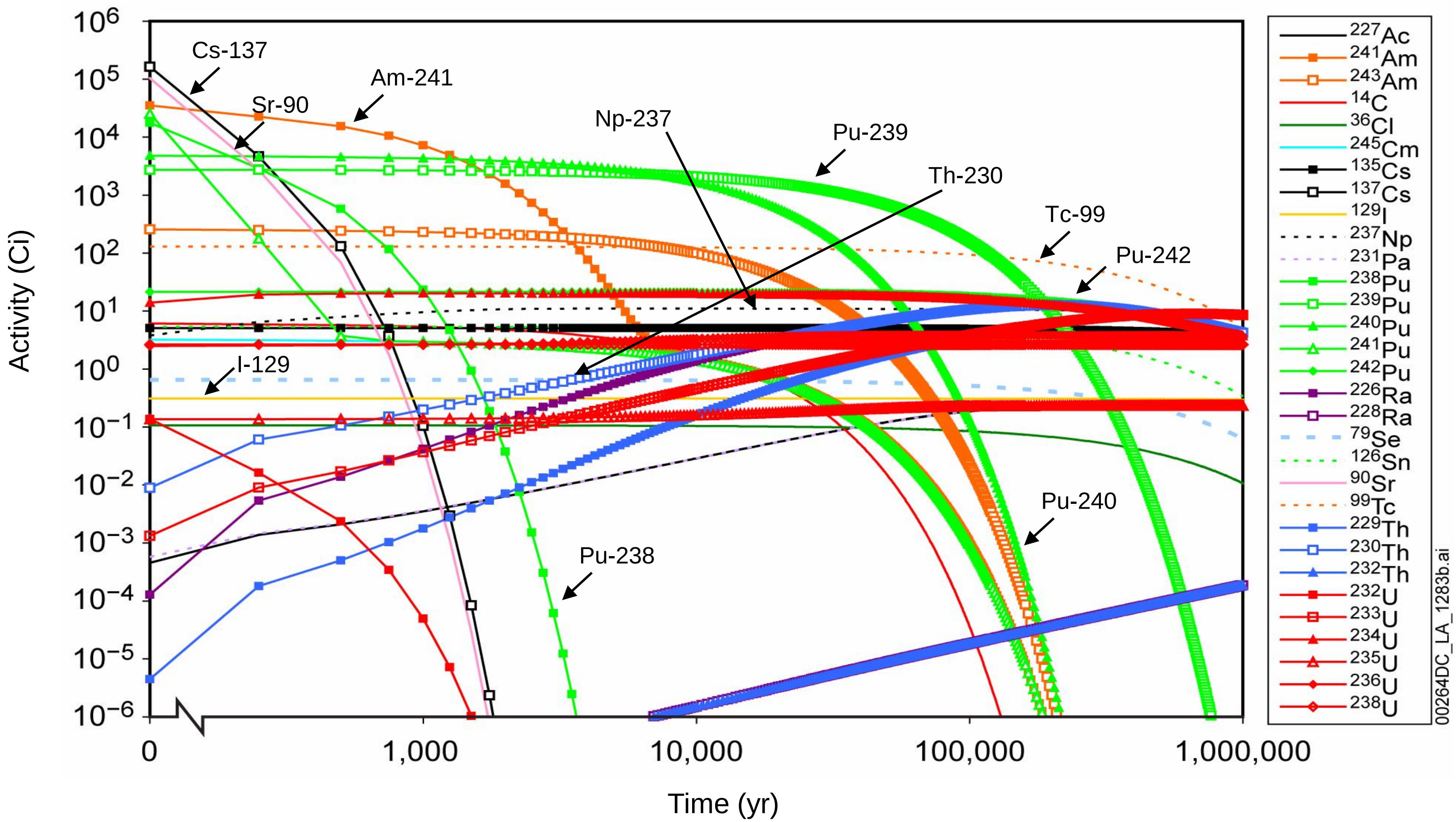
What matters for long-term performance?

- Initial mass (inventory) of dose-contributing radionuclides (or parents)
- Rate of radionuclide releases from waste packages (fast vs. slow)
  - Waste form and waste package degradation rates, radionuclide solubility
- Transport processes/residence time in the engineered barrier system and in the natural system / geosphere
  - Mass spreading: advection, dispersion, diffusion
  - Mass retention/loss: sorption, decay



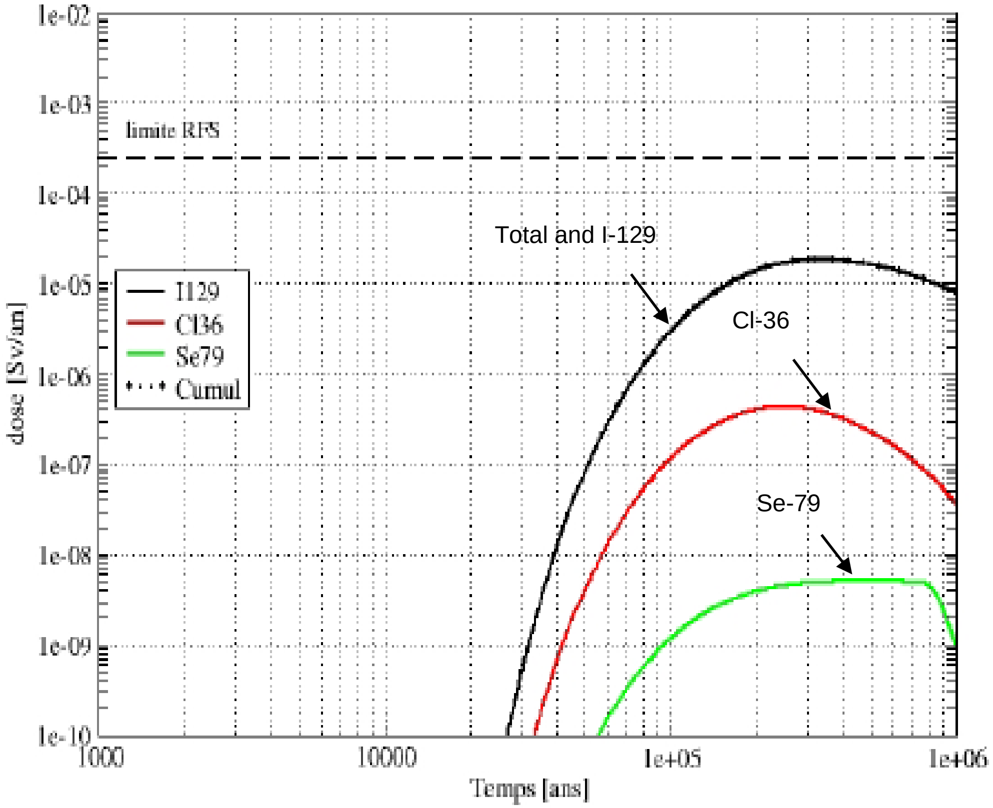
Freeze and Lee, 2011, Proceedings of the 2011 International High-Level Radioactive Waste Management Conference

Commercial Used 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: Meuse / Haute Marne Site (France)

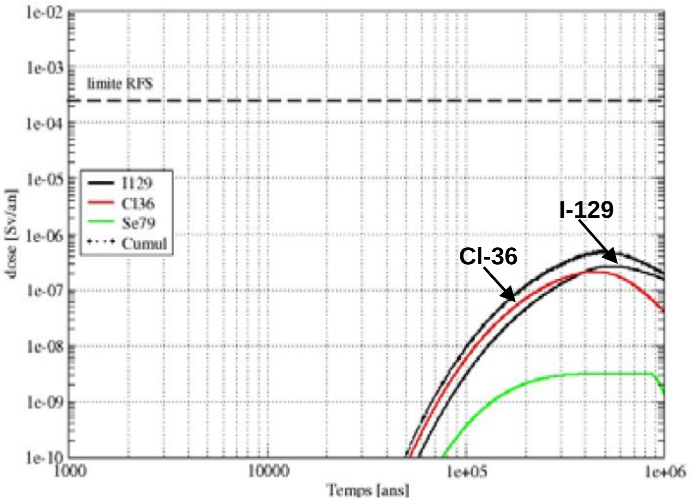


ANDRA 2005, *Dossier 2005: Argile. Tome: Evaluation of the Feasibility of a Geological Repository in an Argillaceous Formation*, Figure 5.5-18, SEN million year model, CU1 spent nuclear fuel and Figure 5.5-22, SEN million year model, C1+C2 vitrified waste

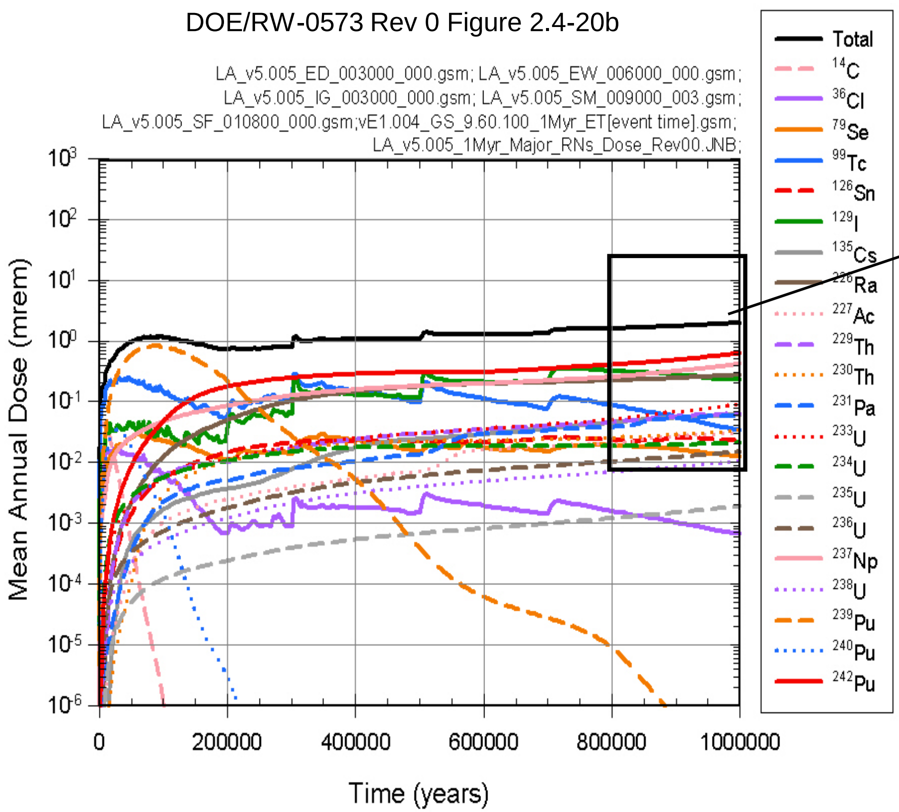
Diffusion-dominated disposal concept: Argillite

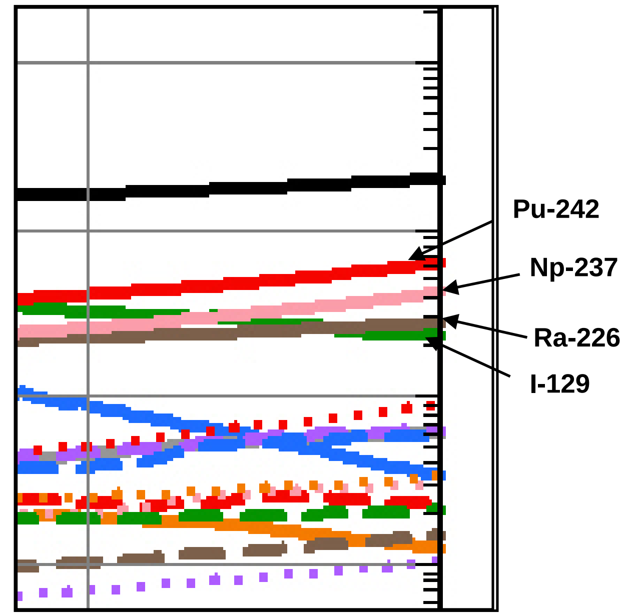
I-129 is the dominant contributor at peak dose

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



Contributors to Total Dose: 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

Contributors to Total Dose: Forsmark site (Sweden)

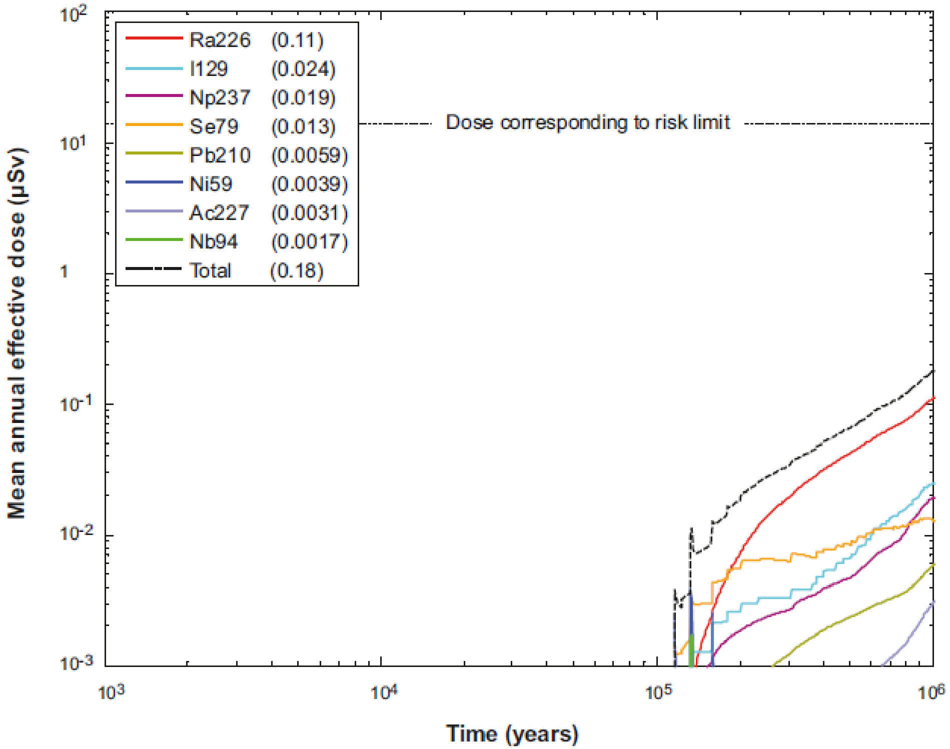


Figure 13-18. Far-field mean annual effective dose for the same case as in Figure 13-17. The legends are sorted according to descending peak mean annual effective dose over one million years (given in brackets in µSv).

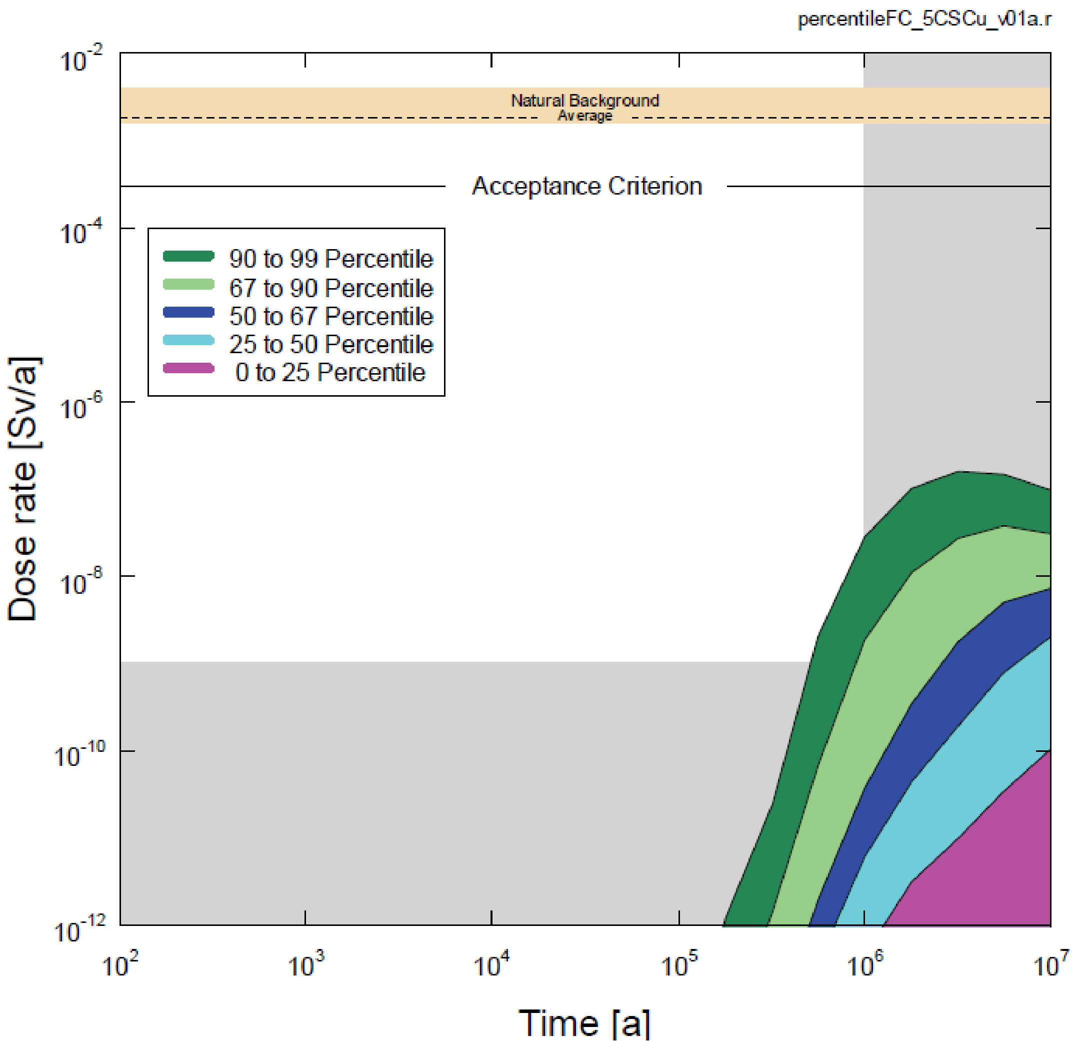
SKB 2011, Long-term safety for the final repository for spent nuclear fuel at Forsmark, Technical Report TR-11-01

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

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

- All nations with significant quantities of spent nuclear fuel and/or high-level radioactive waste are investigating options for deep geologic disposal
- Published analyses of deep geologic disposal of spent nuclear fuel and high-level radioactive waste indicate that multiple disposal concepts in a range of rock types have the potential for excellent long-term performance
- Isolation can be achieved by a combination of natural (i.e., geologic) barriers and engineered barriers working together
- Estimates of peak dose may be dominated by different radionuclides in different disposal concepts

References

ANDRA Agence nationale pour la gestion des déchets radioactifs), *Dossier 2005: Argile. Tome: Safety Evaluation of a Geological Repository* (English translation: original documentation written in French remains ultimately the reference documentation), 2005, http://www.andra.fr/international/pages/en/menu21/waste-management/research-and-development/dossier-2005-1636.html

Freeze, G.A., and J.H. Lee, 2011, *A Simplified Performance Assessment (PA) Model for Radioactive Waste Disposal Alternatives*, proceedings of the 2011 International High-Level Radioactive Waste Management Conference, April 10-14, 2011, Albuquerque, NM.

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

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.

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