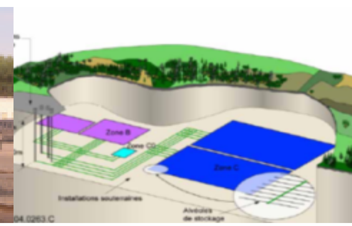
SAND2022-2534C

Geologic Disposal of High Activity Radioactive Waste, Waste Forms, and Waste Streams: Considerations for Disposal



Waste Management 2022
SAND2022-XXXX

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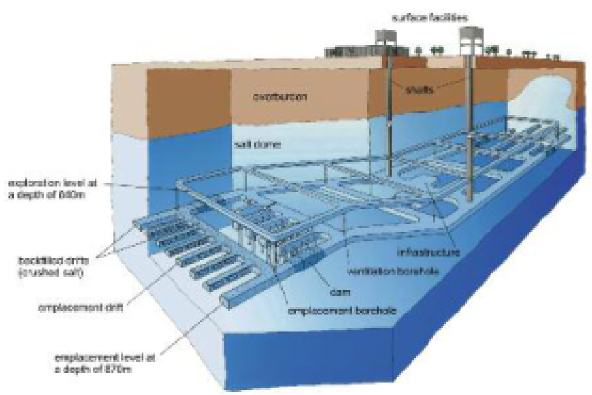
Outline

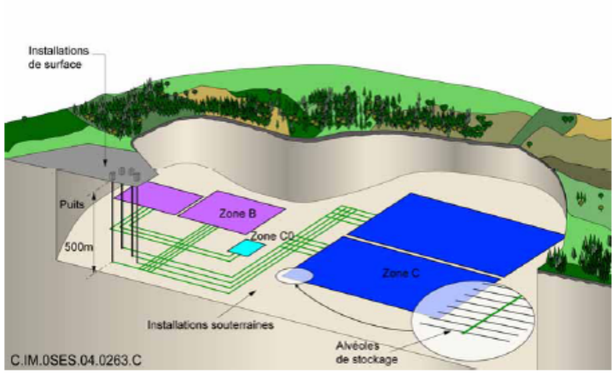
- Disposal concepts
- Waste characteristics affecting disposal
- How alternative nuclear fuel cycles might change waste forms requiring deep geologic disposal
- How existing safety assessments inform observations about the impacts of such changes on repository performance (examples from multiple programs)
- Conclusions

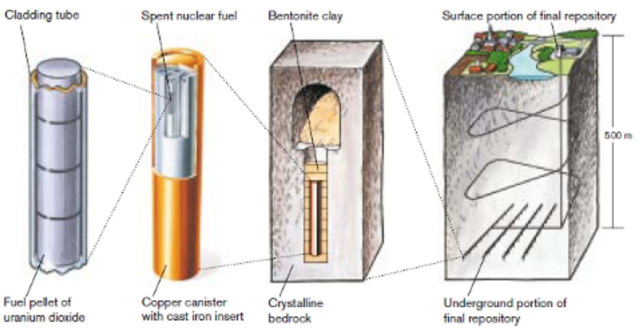
Deep Geological Disposal for Spent Nuclear Fuel and High-Level Radioactive Waste

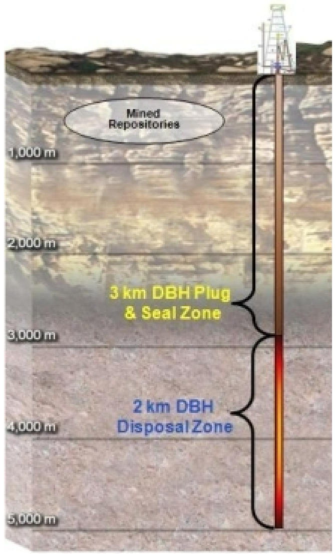
Deep geologic disposal has been planned since the 1950s

> "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









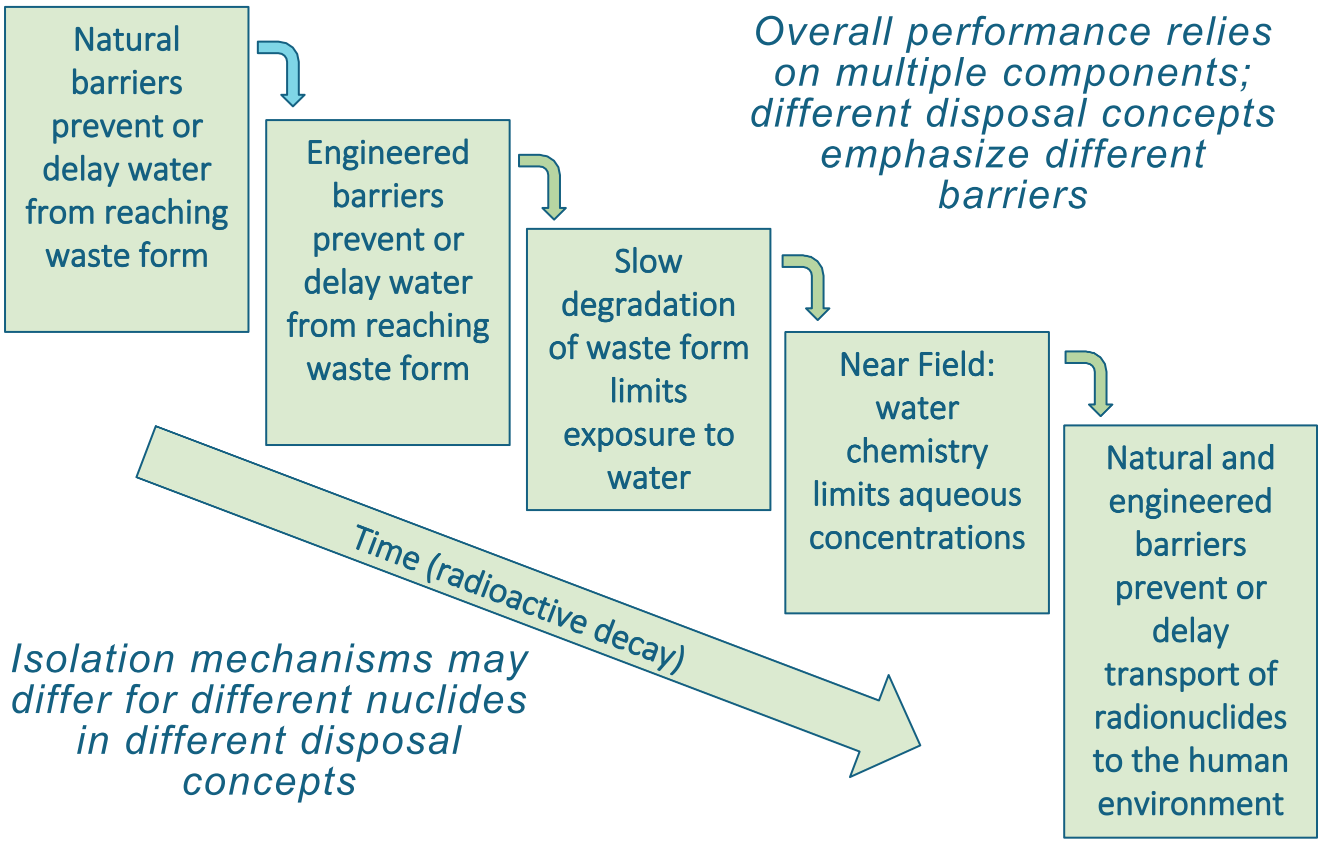
Status of Deep Geologic Disposal Programs World-Wide

Nation	Host Rock	Status
Finland	Granitic Gneiss	Construction license granted 2015. Submitted application for operating license Dec. 2021
Sweden	Granite	License application submitted 2011 Local municipalities gave approval Oct. 2020 Swedish government approved final repository system 2022
France	Argillite	Construction operations planned to begin 2022
Canada	Granite, sedimentary rock	Candidate sites being identified
China	Granite	Repository proposed in 2050
Russia	Granite, gneiss	Decision on repository construction in 2025
Germany	Salt, other	Uncertain
USA	Salt (transuranic waste at the Waste Isolation Pilot Plant) Volcanic Tuff (Yucca Mountain)	WIPP: operating Yucca Mountain: suspended
Japan	TBD	Candidate sites being identified
South Korea	TBD	Candidate sites being identified

Others: Belgium (clay), UK (selecting site), Spain (uncertain), Switzerland (clay), Czech Republic (selecting site), all nations with nuclear power.

Sources: Faybishenko et al. 2016; World Nuclear News 2020; SKB 2022; Posiva Oy 2019 and 2022; ABC News 2020; Wiley Online Library 2020; World Nuclear Association 2022

How Repositories Work



Technical Characteristics/Properties of Waste Forms to be Considered for Disposal Strategy

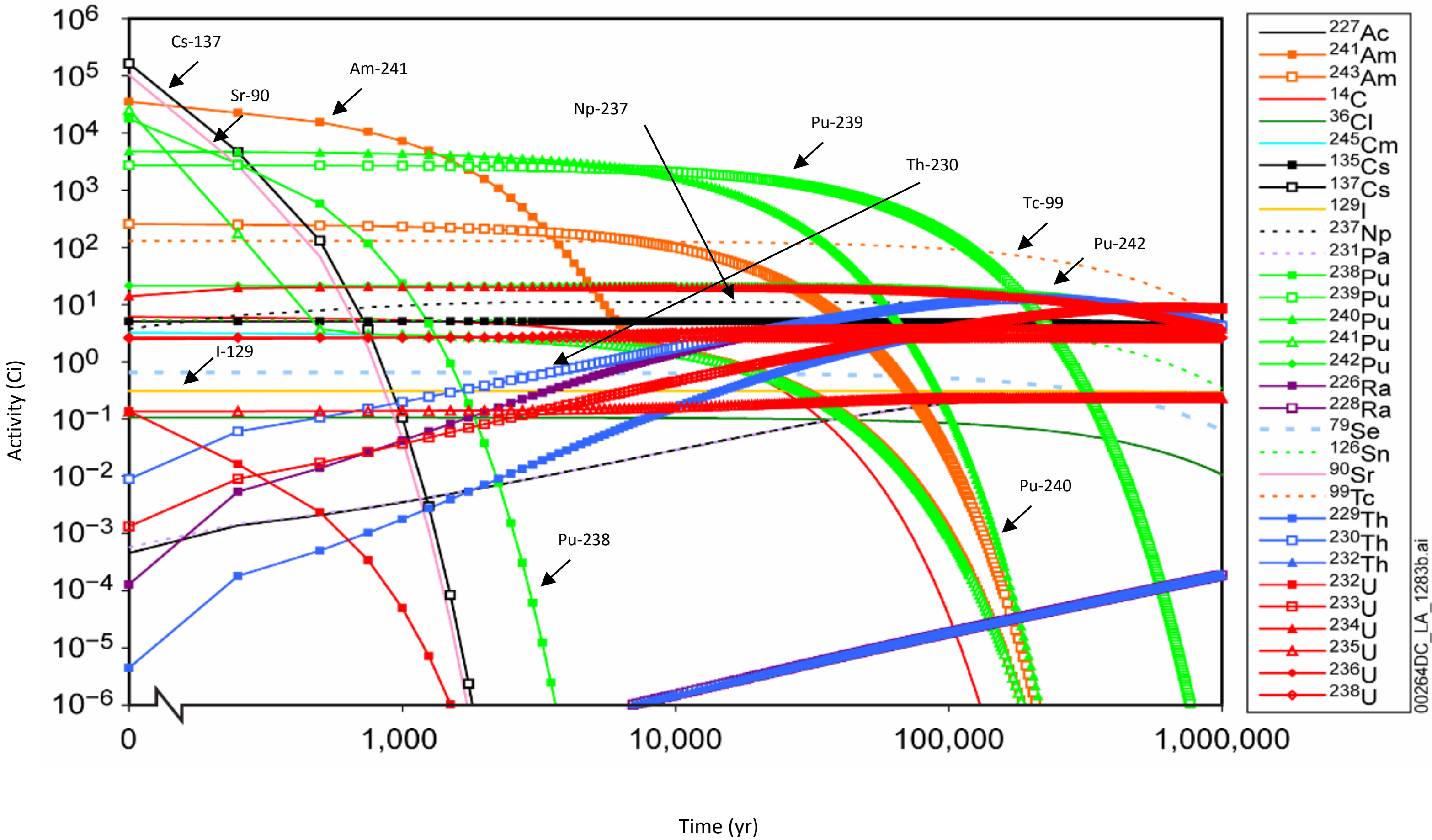
- Waste forms should be disposable in any of the possible generic geologic disposal concepts
  - Not striving to optimize waste forms and disposal geologies
- Potential for criticality over repository time scales
  - Current SNF dry storage canisters designed to prevent criticality over timescales commensurate with storage and transport, not disposal
  - Would have to be evaluated for High Assay Low Enriched Uranium (HALEU)
- Thermal output per waste package
  - Thermal limits per waste package vary by repository concept: geologic media and repository design
  - Options include repackaging, long-term above-ground storage, spacing of waste packages and drifts
  - Waste volume and thermal power density are, to a first approximation, inversely related
- Whether it is vigorously reactive to water (e.g., Na-bonded spent fuel)
- Waste form degradation rate (e.g., salt waste)
  - Uncertainty in fuel dissolution rate can be a dominant contributor to uncertainty in modeled total dose estimates for sites with relatively rapid transport
- Rate of gas generation (e.g., fluoride-based salt from MSR)

How Might Alternative Nuclear Fuel Cycles Impact Geological Disposal?

- For a given amount of electric power, alternative fission-based nuclear fuel cycles may result in:
  - Changes in the radionuclide inventory
    - *Reprocessing can reduce actinide content of final waste product*
    - *But actinides not always largest contributor to dose*
    - *Increased fissile content (e.g., HALEU)*
  - Changes in the volume of waste
    - *Reprocessing can reduce the volume of waste requiring deep geologic disposal*
    - *But cost of disposal not necessarily reduced significantly*
  - Changes in the thermal power of the waste
    - *Separation of minor actinides can reduce thermal power of the final waste form*
    - *But fission products are the major contributor to thermal power in first century and still need to be disposed of*
    - *Cs-135 ($t_{1/2}$ = 2.3 million years) separates out with Cs-137*
  - Changes in the durability of the waste in repository environments
    - *Treatment of waste streams can create more durable waste forms*
    - *More durable waste form desirable for all disposal geologies*
- For each potential change, consider
  - How will these changes impact repository safety?
  - How will these changes impact repository cost and efficiency?

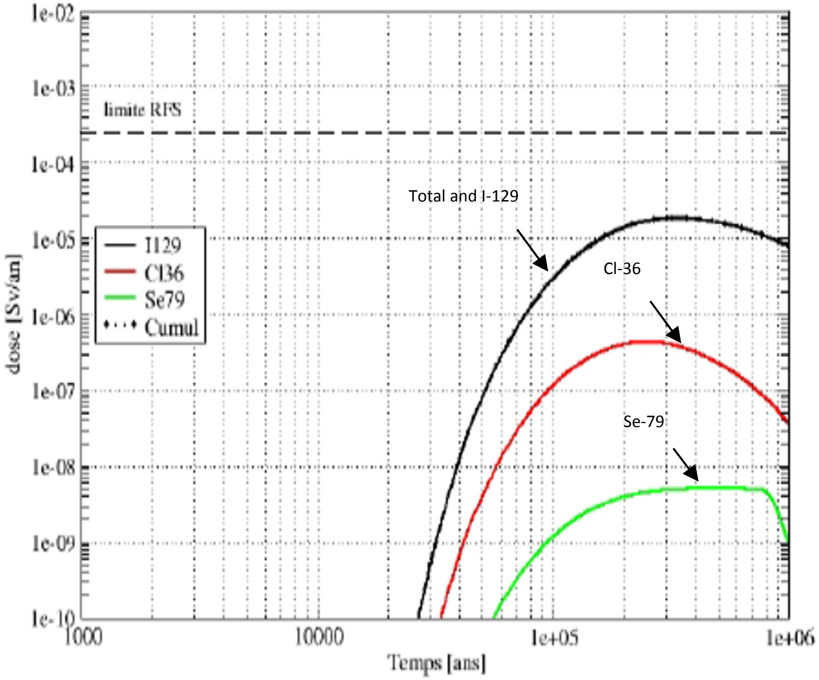
Light-Water Reactor Spent Nuclear Fuel Activity

Example from US Program



DOE/RW-0573 Rev 0, Figure 2.3.7-11, inventory decay shown for a 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)

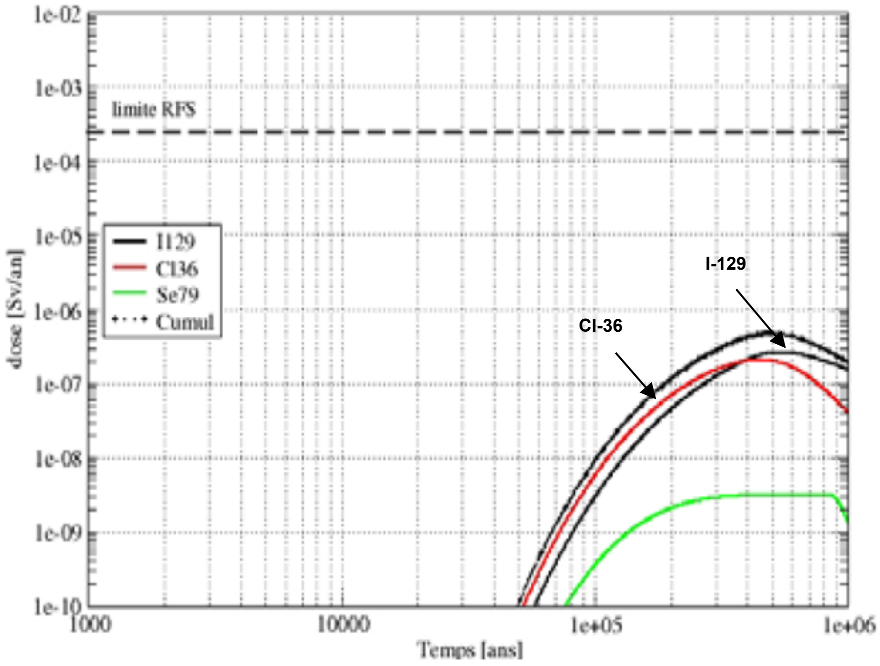


ANDRA 2005, Figure 5.5-18, million year model for spent nuclear fuel disposal and Figure 5.5-22, million year model for vitrified waste disposal

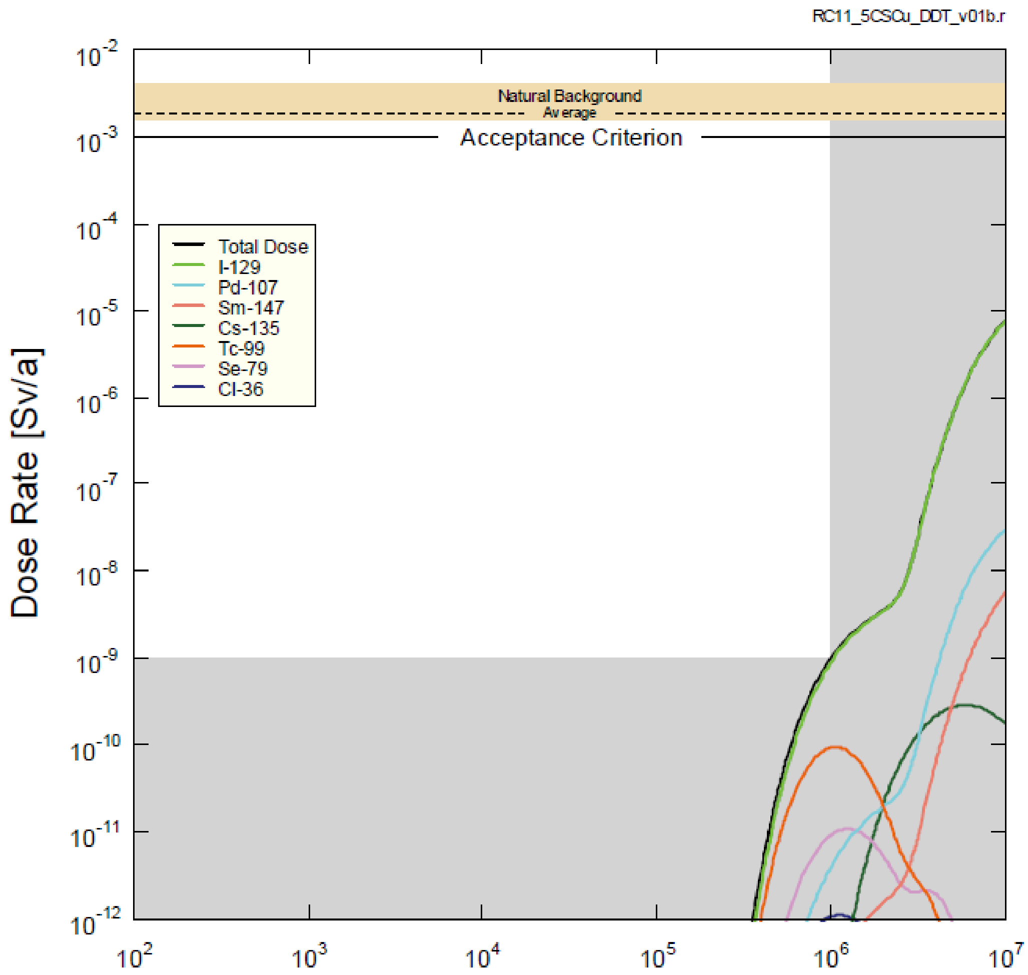
Diffusion-dominated disposal concept: Argillite

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, 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)

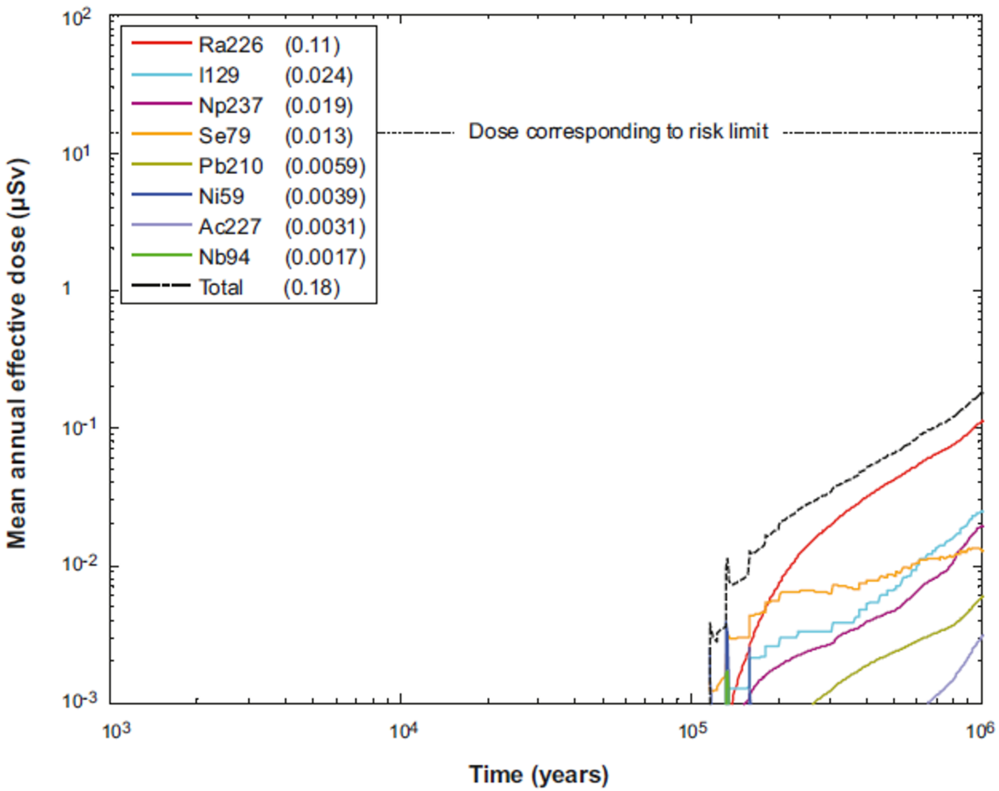


Figure 13-18. *Far-field mean annual effective dose for the same case as in Figure 13-17. The legends are sorted according to descending peak mean annual effective dose over one million years (given in brackets in µSv).*

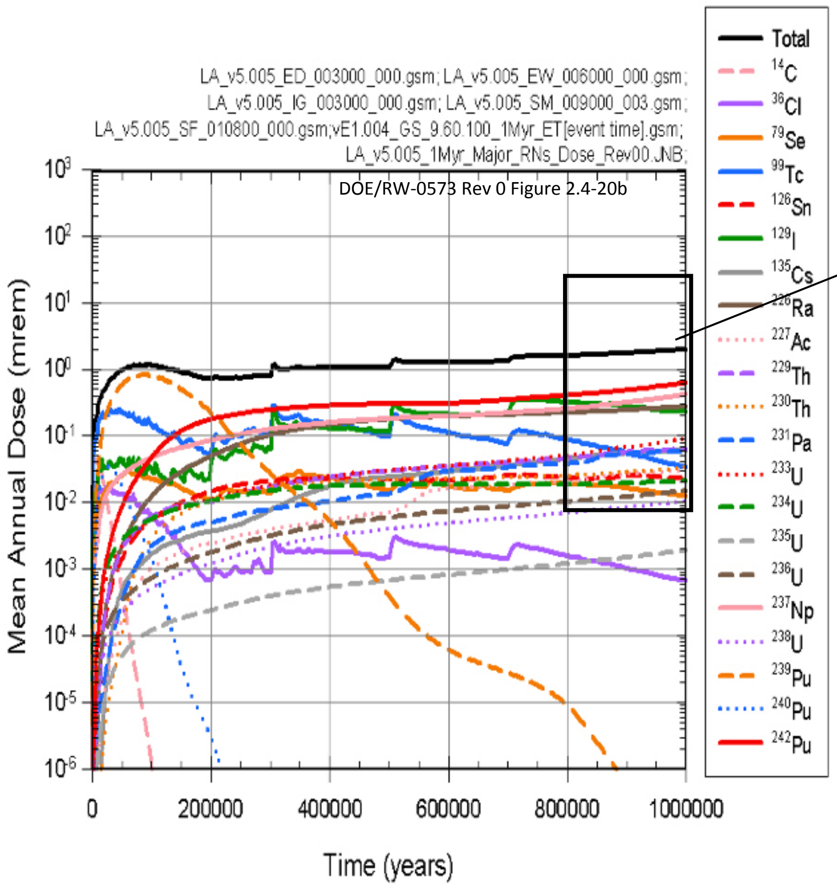
SKB 2011

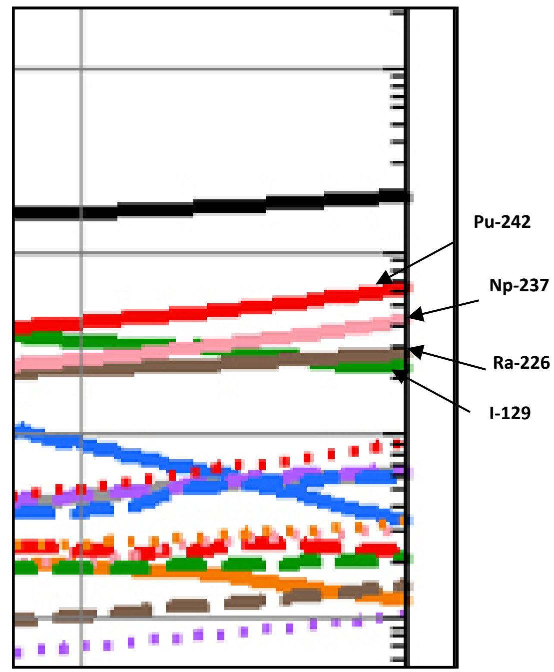
Disposal concept with advective fracture transport in the far-field: Granite

Long-term peak dose dominated by Ra-226

Once waste packages fail via corrosion, 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. 1/10th of total

Conclusions

- U.S. is committed to deep geologic disposal of spent nuclear fuel
- Overall repository performance relies on multiple components; different disposal concepts emphasize different barriers
- Characteristics of waste to be considered for disposal strategy
  - Disposability in any kind of geologic repository
  - Potential for criticality over repository timescales
  - Thermal output per unit of waste
  - Potential for vigorous reaction with water
  - Waste form degradation rate
  - Rate of gas generation
- Contributors to total dose
  - Major contributors to dose are not always the radionuclides with the highest activity
  - Long-term dose estimates in most geologic settings are dominated by mobile species, primarily I-129
  - Other major contributors to long-term dose are other long-lived fission and activation products, and Ra-226, Pu-242, Np-237

References

- ABC News, 2020. "2 Remote Japan towns seek to host nuclear waste storage site," October 9, 2020. ABC News Internet Ventures.
- 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).
- 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.
- 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, 2019. *Annual Report 2019*, Posiva Oy, Olkiluoto, Finland.
- Posiva 2022. https://www.posiva.fi/en/index/news/pressreleasesstockexchangereleases/2021/posivasubmitsapplicationforoperatinglicenceforencapsulationandfinaldisposalfacilityofspentnuclearfuel.html
- 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.
- SKB 2022. https://www.skb.com/news/next-step-following-government-decision/
- US DOE (United States Department of Energy) 2008. Yucca Mountain Repository License Application, DOE/RW-0573, Rev. 1.

References (cont'd)

- Wiley Online Library, 2020. "Managing spent nuclear fuel in South Korea: Heterogeneous public attitudes toward different management strategies at individual and segment levels," International Journal of Energy Research, Volume 44, Issue 10.
- World Nuclear Association 2022. https://world-nuclear.org/information-library/country-profiles.aspx
- World Nuclear News, 2020. "Swedish municipality gives approval for fuel repository," October 14, 2020, World Nuclear Associated, Tower House, 10 Southampton Street, London, WC2E 7HA, UK.