



Applying Insights from Repository Safety Assessments to Evaluating Impacts of Partitioning and Transmutation

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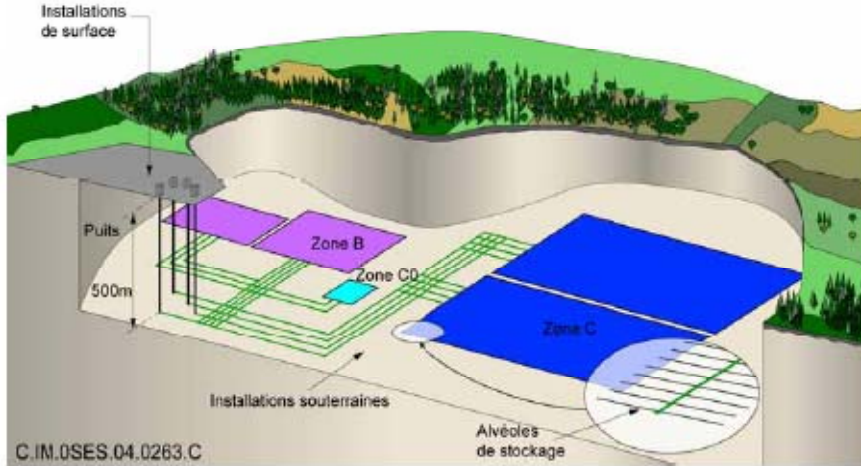
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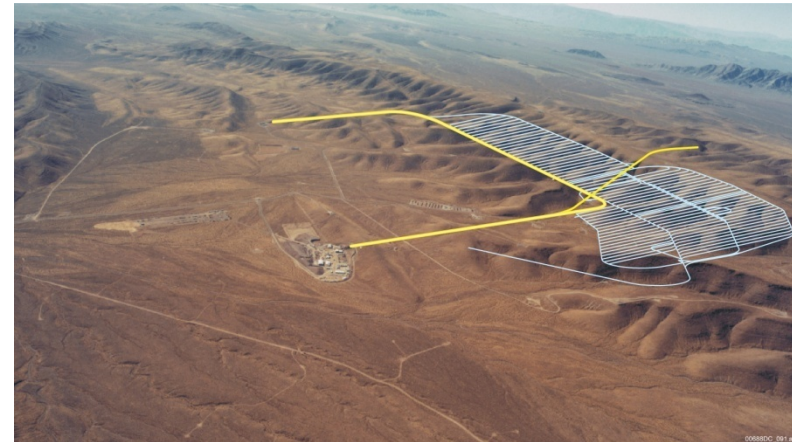
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- **Observations drawn from published safety assessments**
 - **Switzerland: Opalinus Clay, 2002**
 - **France: Dossier 2005 Argile, 2005**
 - **Sweden: SR-Can, 2006**
 - **USA: Yucca Mountain License Application, 2008**
 - **European Commission multi-program “*RED-IMPACT*” study, 2008**
- **Three topics considered**
 - **Radionuclides contributing to total dose**
 - **Thermal loading**
 - **Waste form lifetime**

Detailed Safety Assessments Available for Repositories in Clay, Granite, and Tuff

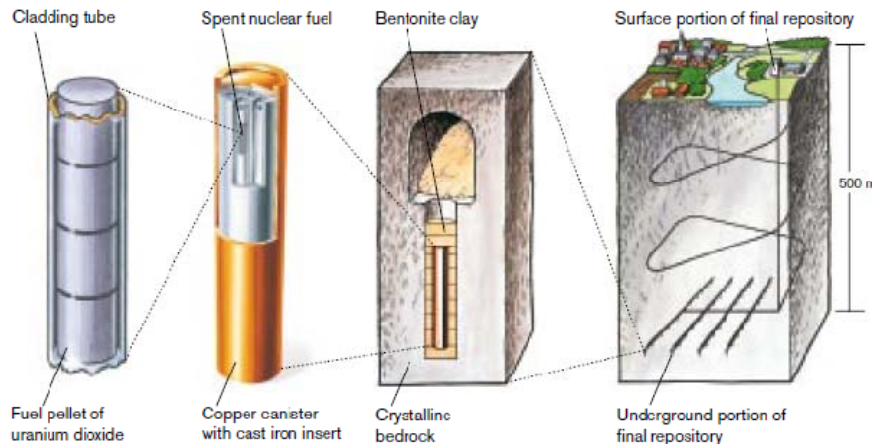


Tuff (USA)



Clay (example from France)

Granite
(example
from Sweden)





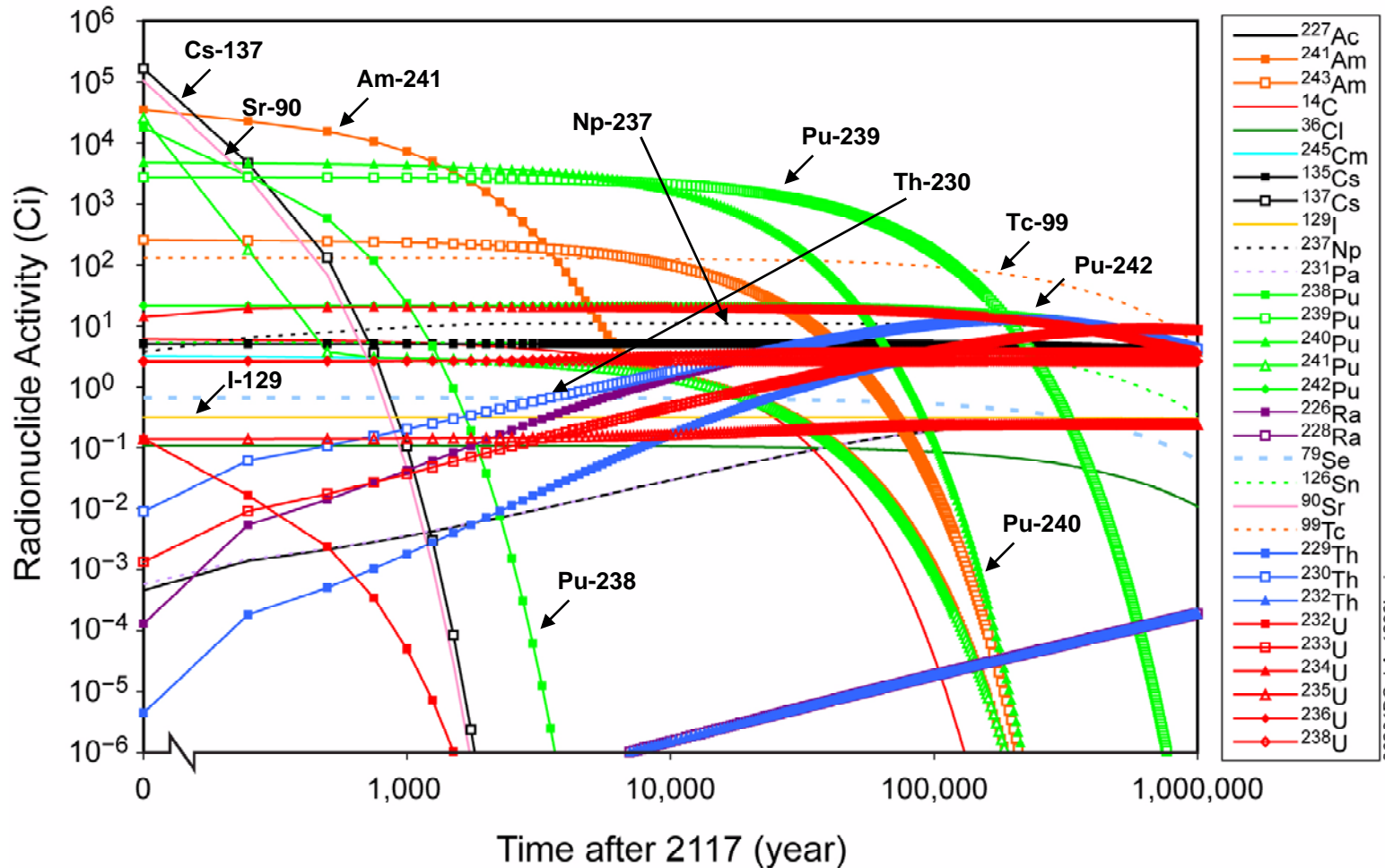
First Order Observations from Published Safety Assessments

- **Estimated long-term doses are very low for each of the disposal concepts that have been analyzed in detail**
 - Multiple approaches to achieving safe isolation
- **Radionuclides contributing to dose vary for different disposal concepts**
 - Water chemistry (redox state) and transport mechanism (advection vs. diffusion) matter
- **Thermal load can be managed through design and operations**
 - All disposal concepts rely on limiting near field temperatures
- **Relative importance of engineered and natural barriers varies for different disposal concepts**
 - The slowest link in the release and transport chain tends to dominate behavior of the system



Radionuclides Contributing to Total Dose

Commercial Used Nuclear Fuel Decay



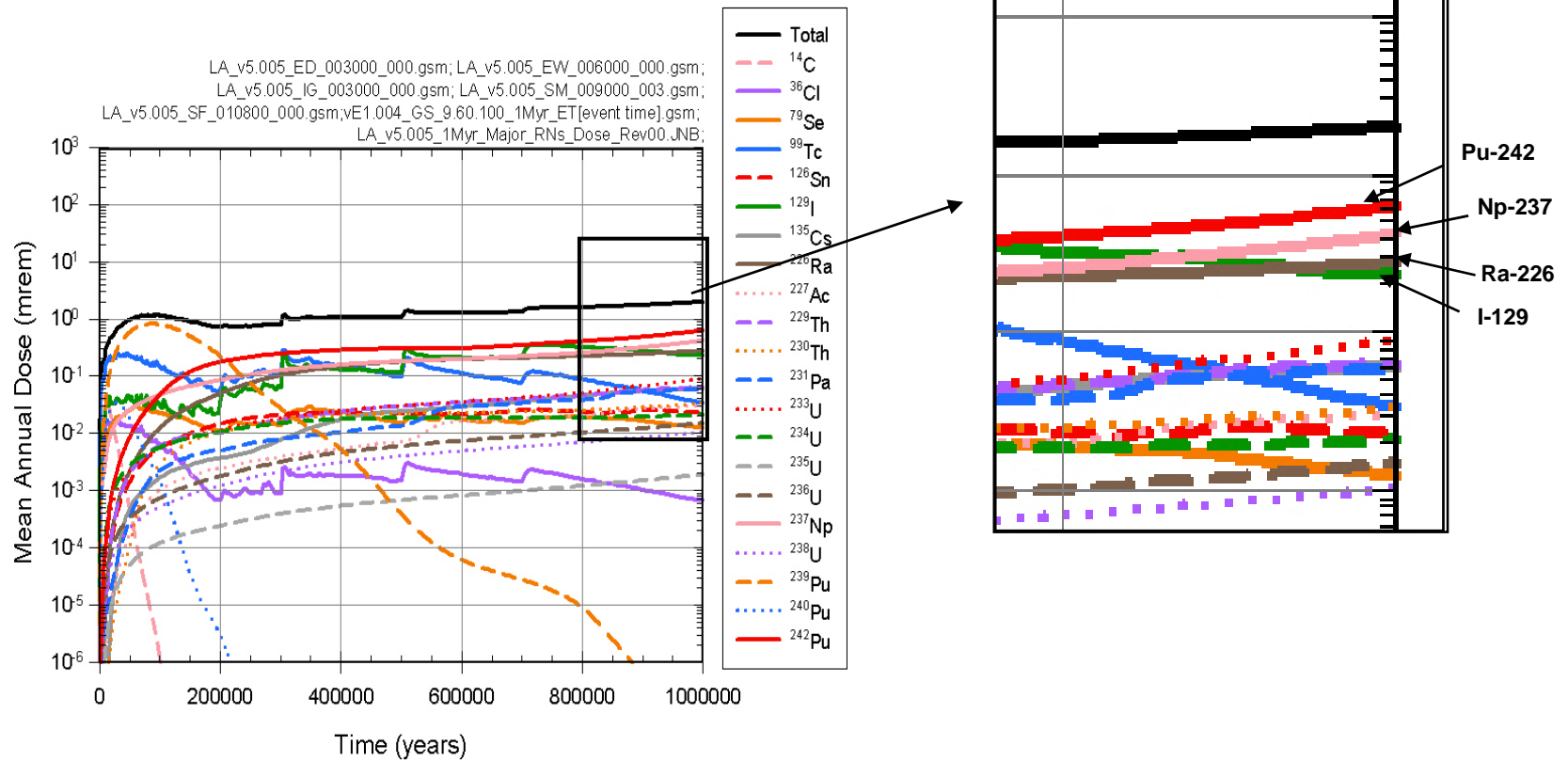
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DOE/RW-0573 Rev 0, Figure 2.3.7-11, inventory decay shown for an single representative Yucca Mountain used fuel waste package, as used in the Yucca Mountain License Application



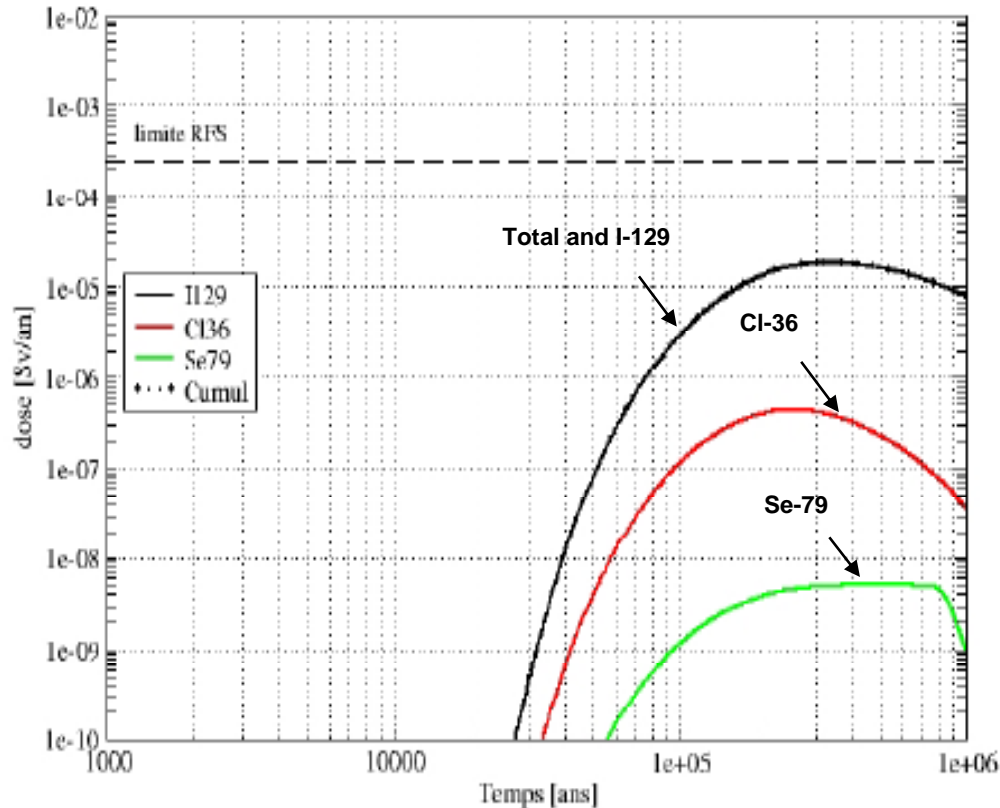
Contributors to total dose: Yucca Mountain

DOE/RW-0573 Rev 0 Figure 2.4-20b





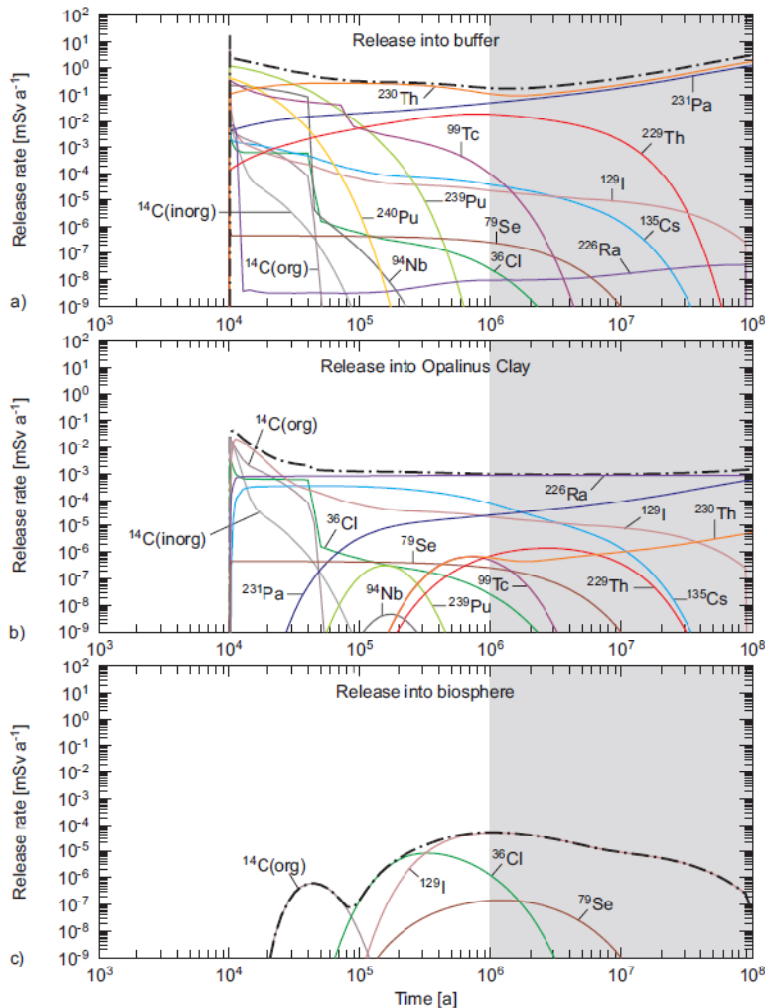
Contributors to total dose: Meuse / Haute Marne Site (France)



I-129 is the dominant contributor at peak dose (example shown for direct disposal of used fuel)

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

Contributors to total dose: Opalinus Clay (Switzerland)



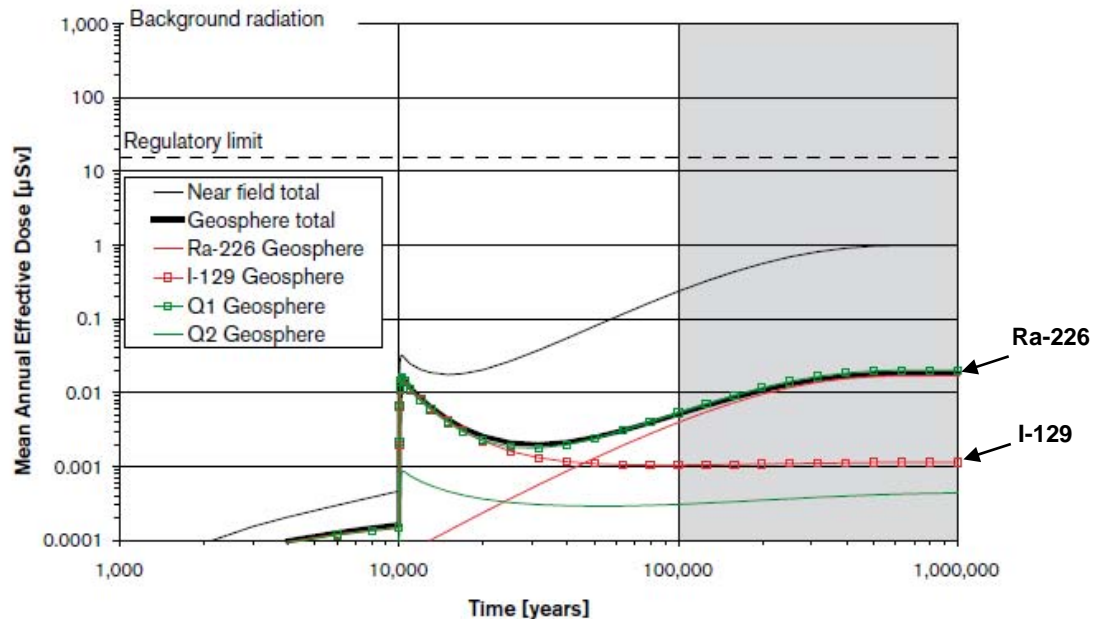
Releases from spent fuel dominated by early spike of I-129 and long-lived actinides (Th-230, Pa-231)

Releases from clay buffer dominated by relatively more mobile Ra-226 and I-129

Releases to biosphere dominated by I-129, Cl-36, C-14, and Se-79

NAGRA 2002, Project Opalinus Clay Safety Report: Démonstration of disposal feasibility for spent fuel, vitrified high-level waste and long-lived intermediate level-waste (Entsorgungsnachweis), Technical Report 02-05, Figure 6.5-1

Contributors to total dose: Forsmark site (Sweden)



Early peak from rapid release of I-129 when package fails (assumed at 10,000 yr for this case)

Long-term peak from Ra-226 controlled by fuel dissolution and diffusion through buffer

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



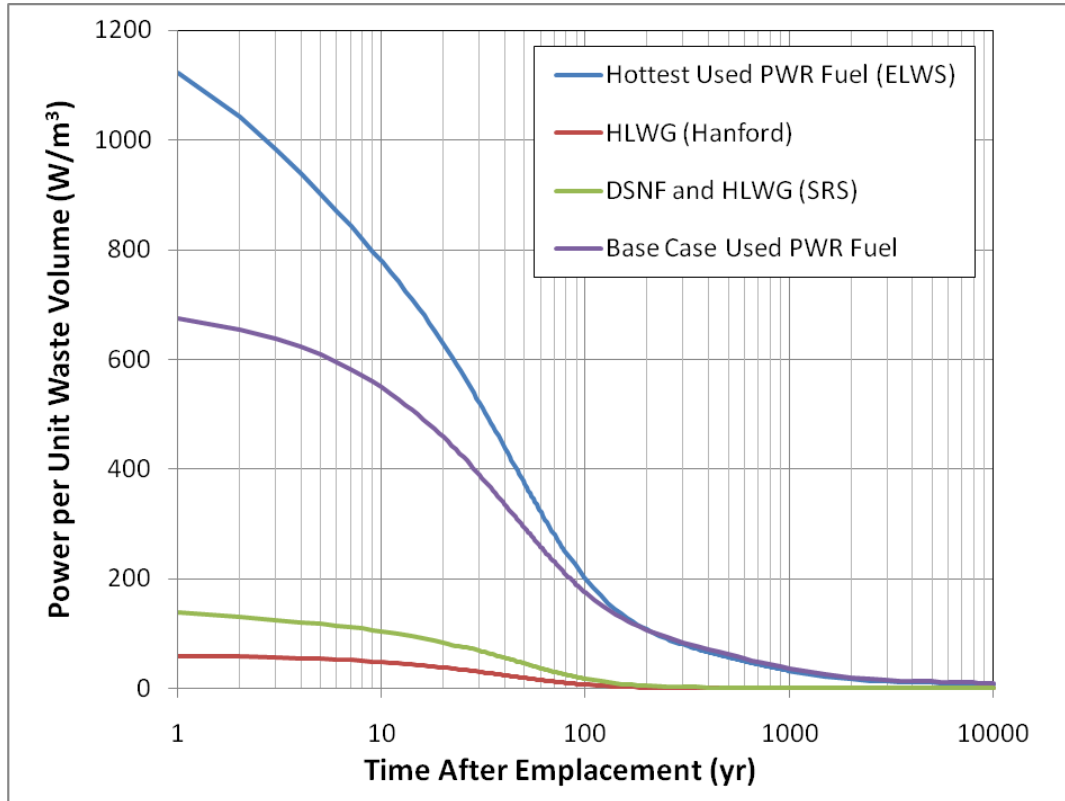
Summary of Radionuclides Contributing to Dose

- **Major contributors to total dose differ for different disposal concepts**
 - **For all disposal concepts, I-129 is likely to be a major contributor at 1 million years**
 - **For oxidizing sites with advective release pathways, actinides may dominate**
 - **For reducing sites with advective release pathways, relatively mobile Ra-226 may be important in addition to fission products**
 - **For disposal concepts dominated by diffusive releases, long-lived mobile fission and activation products are likely to dominate**



Managing Thermal Load

Thermal Objectives for Repositories



- **Yucca Mountain**
 - Below boiling peak temperature at midpoint between emplacement drifts
- **Other disposal concepts**
 - Below boiling peak temperatures in backfill

Calculated thermal power for representative Yucca Mountain waste forms



Options for Achieving Thermal Objectives

- **Repository Design**
 - Size of waste packages
 - Spacing between packages
 - Thermal properties of engineered materials
- **Operational Options**
 - Aging
 - Ventilation
 - Load management
- **Modifications to Waste Forms**
 - Decreasing density of fission-product and actinide loading
 - Separation of heat-generating isotopes



Relative Contributions of Waste Form Lifetime



Waste Form Lifetime Example: Meuse / Haute Marne Site

- **Used Fuel**

- **Base case: gradual release from fuel matrix over ~50,000 yr (Andra 2005, page 222)**
- **Sensitivity analysis assumes 10× increase in degradation rate (Andra 2005, page 325)**
- **Increasing fuel degradation rate has essentially no impact on modeled time or magnitude of radionuclide concentration at outlet**
 - **Modeled releases are controlled by diffusive transport in clay**

Waste Form Lifetime Example: Forsmark Site

- **Used fuel**

- **Fractional dissolution rate range $10^{-6}/\text{yr}$ to $10^{-8}/\text{yr}$**
 - **Corresponding fuel lifetimes: ~ 1 Myr to 100 Myr**
 - **Dissolution rates for oxidizing conditions (not anticipated), up to $10^{-4}/\text{yr}$**
- **Uncertainty in fuel dissolution rate is dominant contributor to uncertainty in modeled total dose estimates**

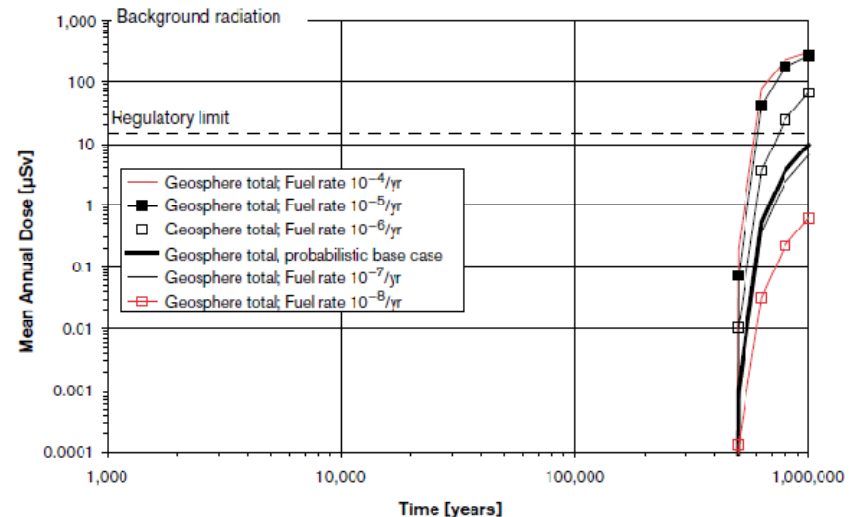


Figure 10-44. Sensitivity of the base case result to the fuel dissolution rate. Semi-correlated hydrogeological DFN model for Forsmark. 1,000 realisations of the analytic model for each case.

Source: SKB 2006, *Long-term Safety for KBS-3 Repositories at Forsmark and Laxemar—a First Evaluation*, TR-06-09, section 10.6.5

Also, SKB 2006, *Fuel and Canister Process Report for the Safety Assessment SR-Can*, TR-06-22, section 2.5.5



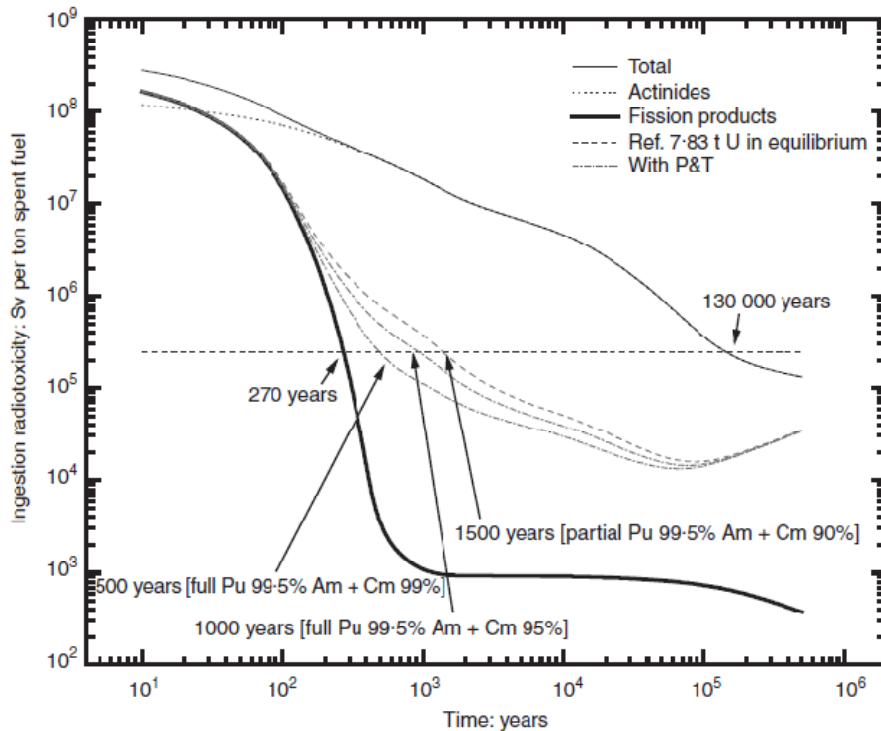
Conclusions

- **Published analyses of geologic repositories indicate potential for excellent long-term performance for a range of disposal concepts**
- **Estimates of peak dose may be dominated by different radionuclides in different disposal concepts**
- **Thermal loading issues can be addressed by design and operational choices**
- **Impact of waste form lifetime on estimates of peak dose varies for different disposal concepts**



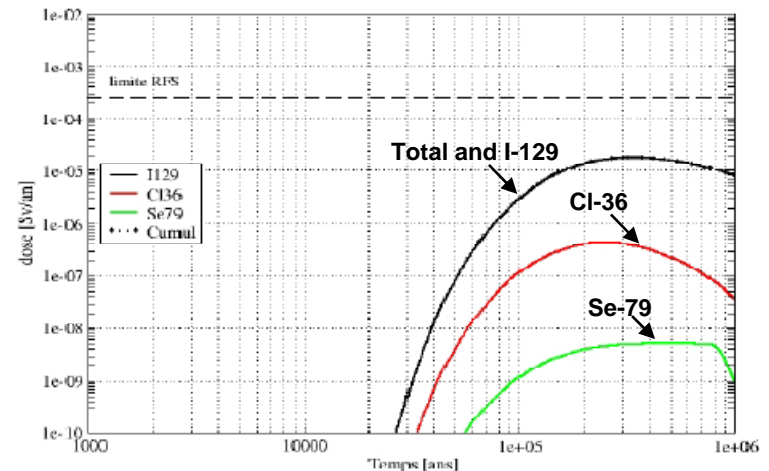
Backup

Radiotoxicity and Dose



Radiotoxicity (left) is dominated by actinides (figure shows reductions associated with different levels of separation)

Estimated dose from disposal of spent fuel (below) is dominated by mobile fission and activation products



Magill et al., 2003, Nuclear Energy v. 42, p. 263-277, Figure 8; doses calculated for ingestion of 1 metric ton of spent nuclear fuel, based on ICRP-72 dose coefficients, showing reductions associated with different levels of actinide separation.

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



Waste Form Lifetime Example: Meuse / Haute Marne Site (cont.)

- HLW

- Base case model: glass “release periods on the order of a few hundred thousand years” (degradation rate decreases when surrounding medium is saturated in silica: Andra 2005, p. 221)
- Sensitivity analysis assuming rapid degradation (100s to 1000s of yr) accelerates peak concentrations at outlet by ~200 kyr, modest increase in magnitude of modeled peak dose
 - For rapid degradation case, modeled releases are controlled by diffusive transport time in clay

	Maximum molar flow exiting Callovo-Oxfordian (mol/yr) and maximum dates (yrs.)	
	Reference	Sensitivity
^{129}I	$8.6 \cdot 10^{-4}$ 460,000 yrs	$9.1 \cdot 10^{-4}$ 250,000 yrs
^{36}Cl	$2.2 \cdot 10^{-4}$ 380,000 yrs	$3.8 \cdot 10^{-4}$ 190,000 yrs

Table 5.5-24 SEN - Attenuation ^{129}I and ^{36}Cl - C1+C2 - comparison between the models $V_0.S$ (sensitivity) and the model $V_0.S \rightarrow V_r$



Waste Form Lifetime Yucca Mountain

- **Used fuel**
 - Modeled half lives conditional on environmental conditions range from 11 yr to 14,000 yr
 - Degradation is slowest at lower T, neutral pH, and small specific surface area
- **HLW**
 - Modeled half lives conditional on environmental conditions range from 29 yr to 1.4×10^8 yr
 - Degradation is slowest at lower T, mildly alkaline pH, and low surface area
 - Distribution is strongly skewed toward rapid degradation: as modeled, most glass degrades within 5000 yr of package breach

Source: DOE 2009, DOE response to NRC request for additional information RAI 3.2.2.1.1-005, ADAMS # ML090400542, page 52-56