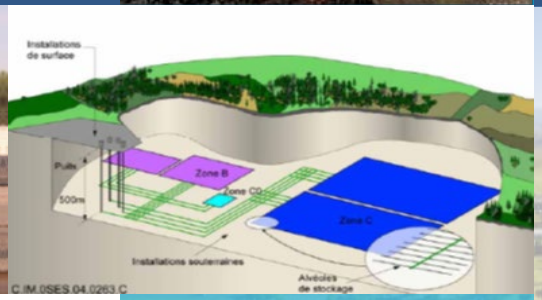
Status of the U.S. R&D Program on Deep Geologic Disposal of Radioactive Waste



Presented by

David Sassani and Peter Swift

Spent Fuel Workshop 2019

November 14, 2019, Ghent, Belgium

Sassani and Swift 2019
Spent Fuel Workshop
November 14-15, 2019
SAND2019-13664 C

Outline

- Status of the US program
  - Background
  - US repository program status
  - Accumulation of commercial spent fuel inventory
  - Observations and future options
  - Other US radioactive wastes
- Options for Geologic Disposal in the US and Other Nations
- Summary and Conclusions

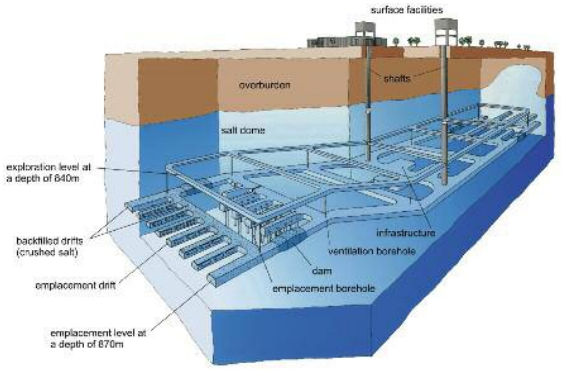
Deep Geological Disposal for Spent Nuclear Fuel and High-Level Radioactive Waste

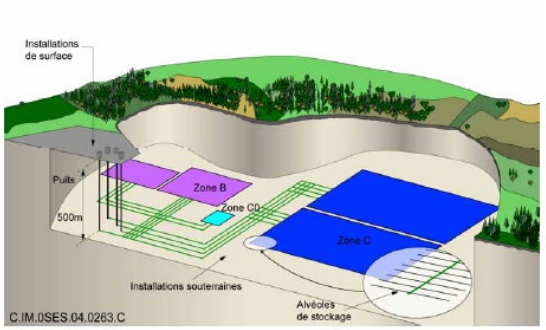
"There has been, for decades, a worldwide consensus in the nuclear technical community for disposal through geological isolation of high-level waste (HLW), including spent nuclear fuel (SNF)."

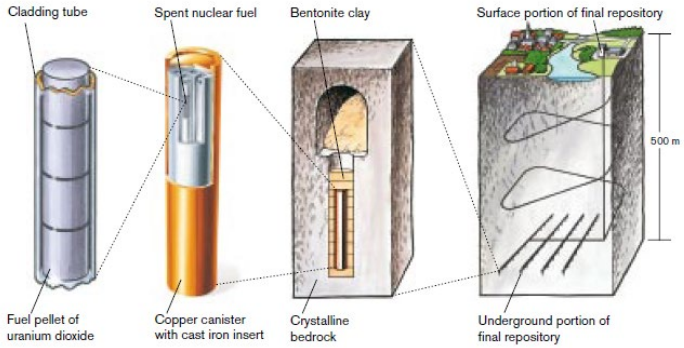
"Geological disposal remains the only long-term solution available."

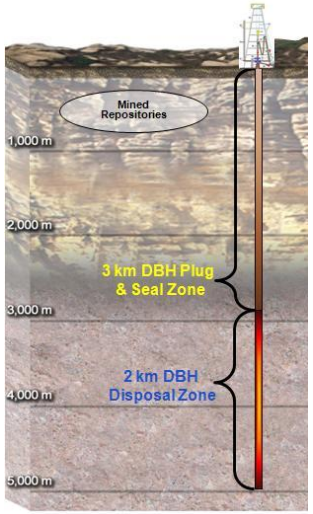
National Research Council, 2001

Deep geologic disposal has been planned since the 1950s









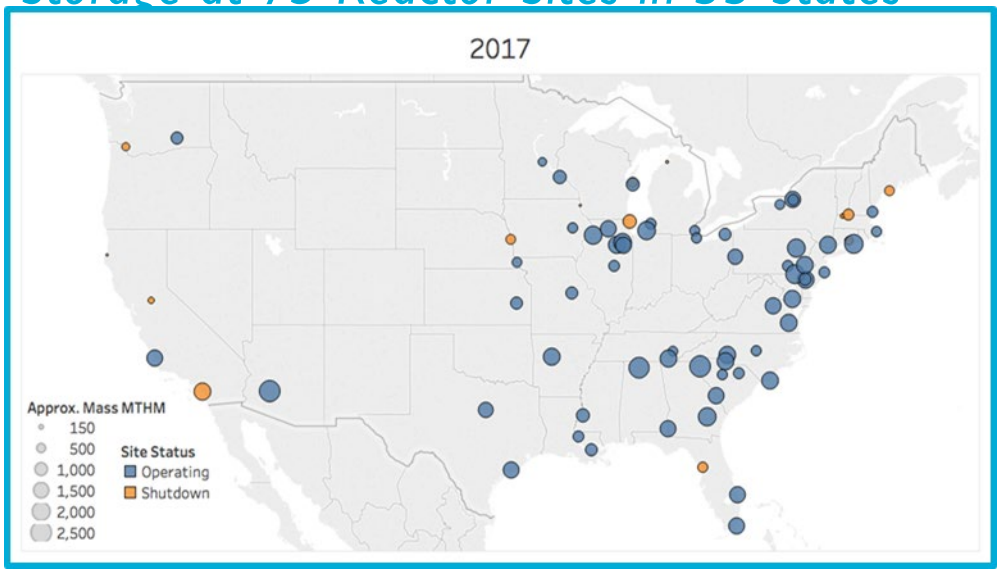
Current Status of the US Program

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
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 and initiates first phase of public interactions planning for a consent-based siting process for both storage and disposal facilities. (Both activities terminated in 2017.)
2016-18	Private sector applications to the NRC for consolidated interim storage (Waste Control Specialists [now Interim Storage Partners] in Andrews, TX and Holtec in Eddy/Lea Counties, NM)
2019	Yucca Mountain licensing process remains suspended, and approximately 300 technical contentions remain to be heard before a licensing board can reach a decision

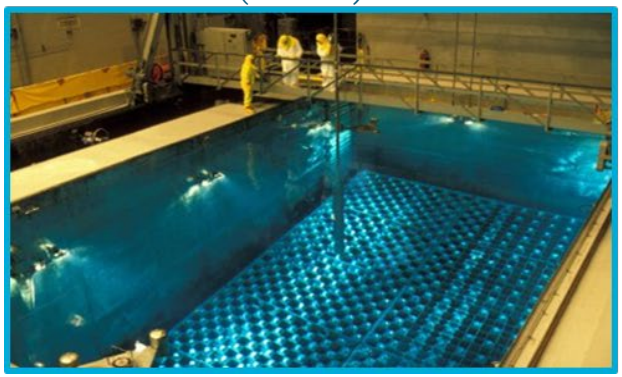
SNF Management in the US: The Reality

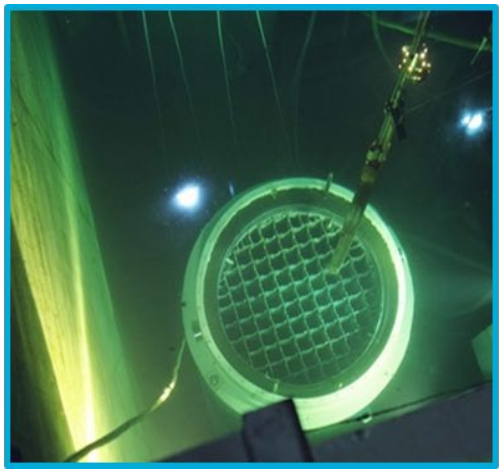
Commercial SNF is in Temporary Storage at 75 Reactor Sites in 33 States

- 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 installation (ISFSI)

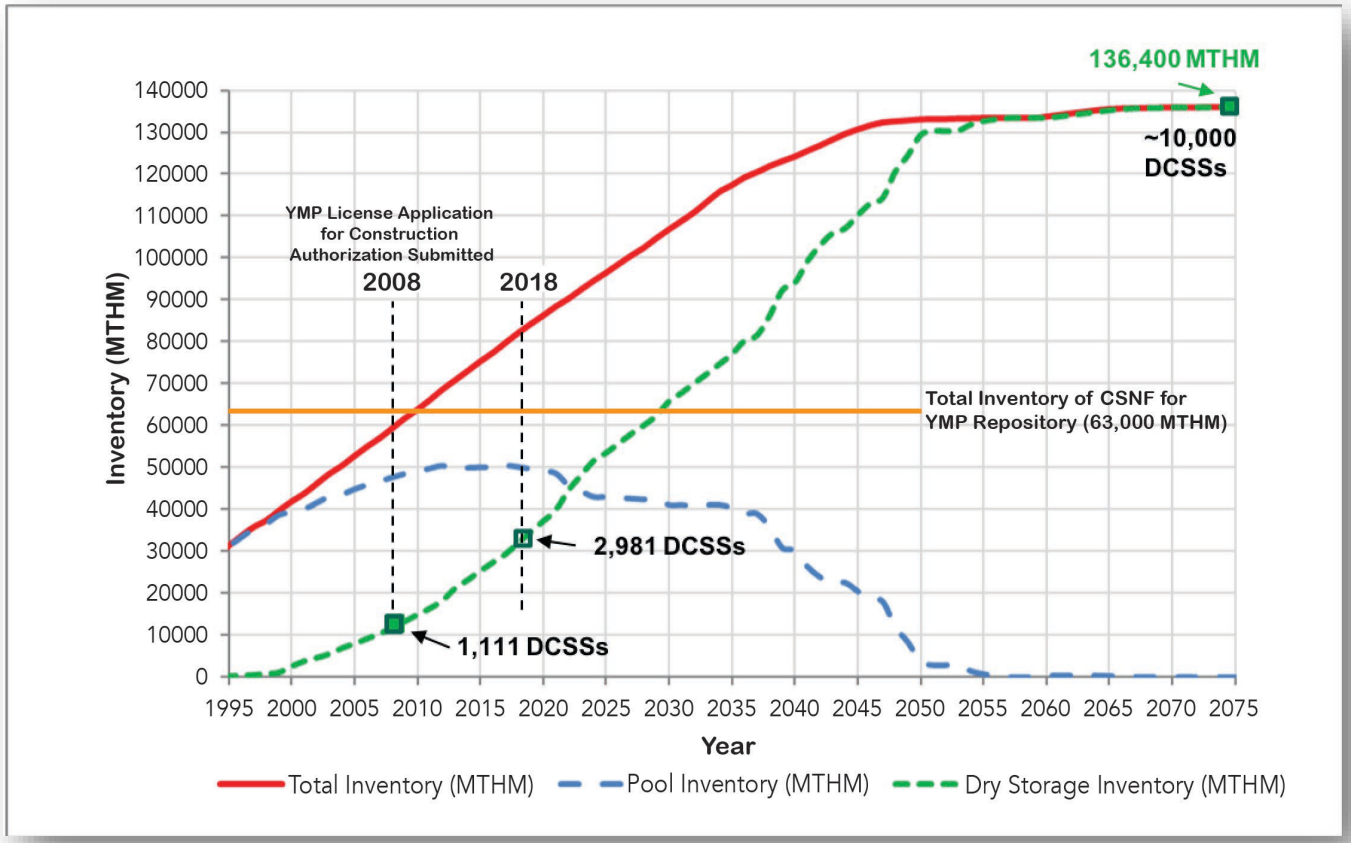


Map of the US commercial SNF storage from Bonano et al. 2018





US Projections of Commercial SNF Inventory



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

Approx. 80,000 MTHM (metric tons heavy metal) of commercial SNF in storage in the US as of Dec. 2017

Approx. 30,000 MTHM in dry storage at reactor sites, in ~2,900 Dry Cask Storage Systems (DCSS)

- Balance in pools, mainly at reactors

Approx. 2200 MTHM of SNF generated nationwide each year

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

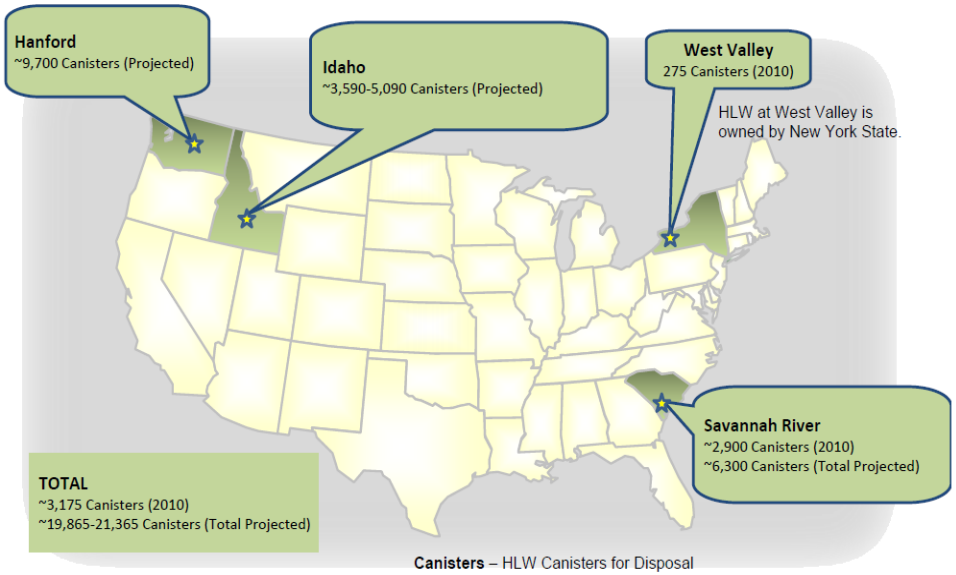
2) Constructing one or more repositories that can accommodate DPCs

3) Storing spent fuel at surface facilities indefinitely, repackaging as needed

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

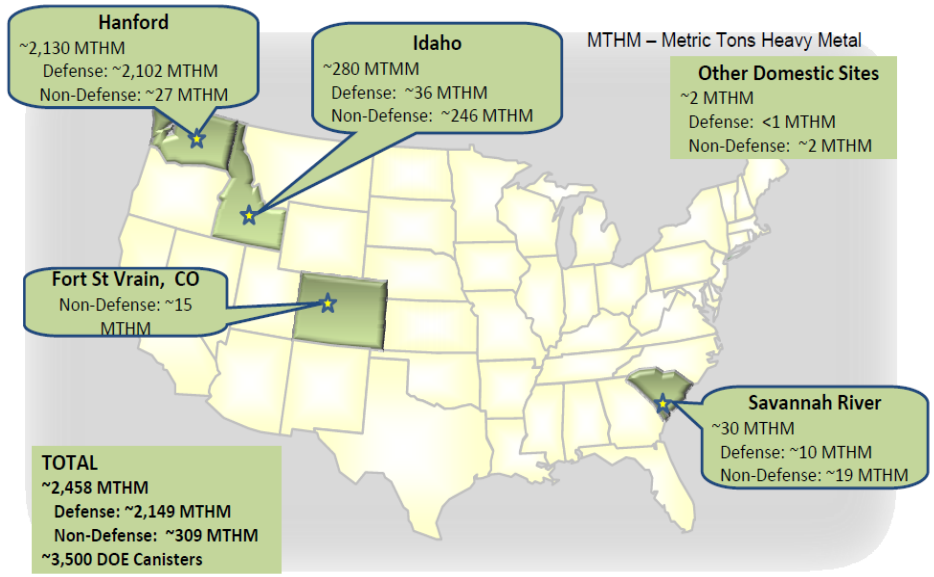
Geologic Disposal in the US: The Reality

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

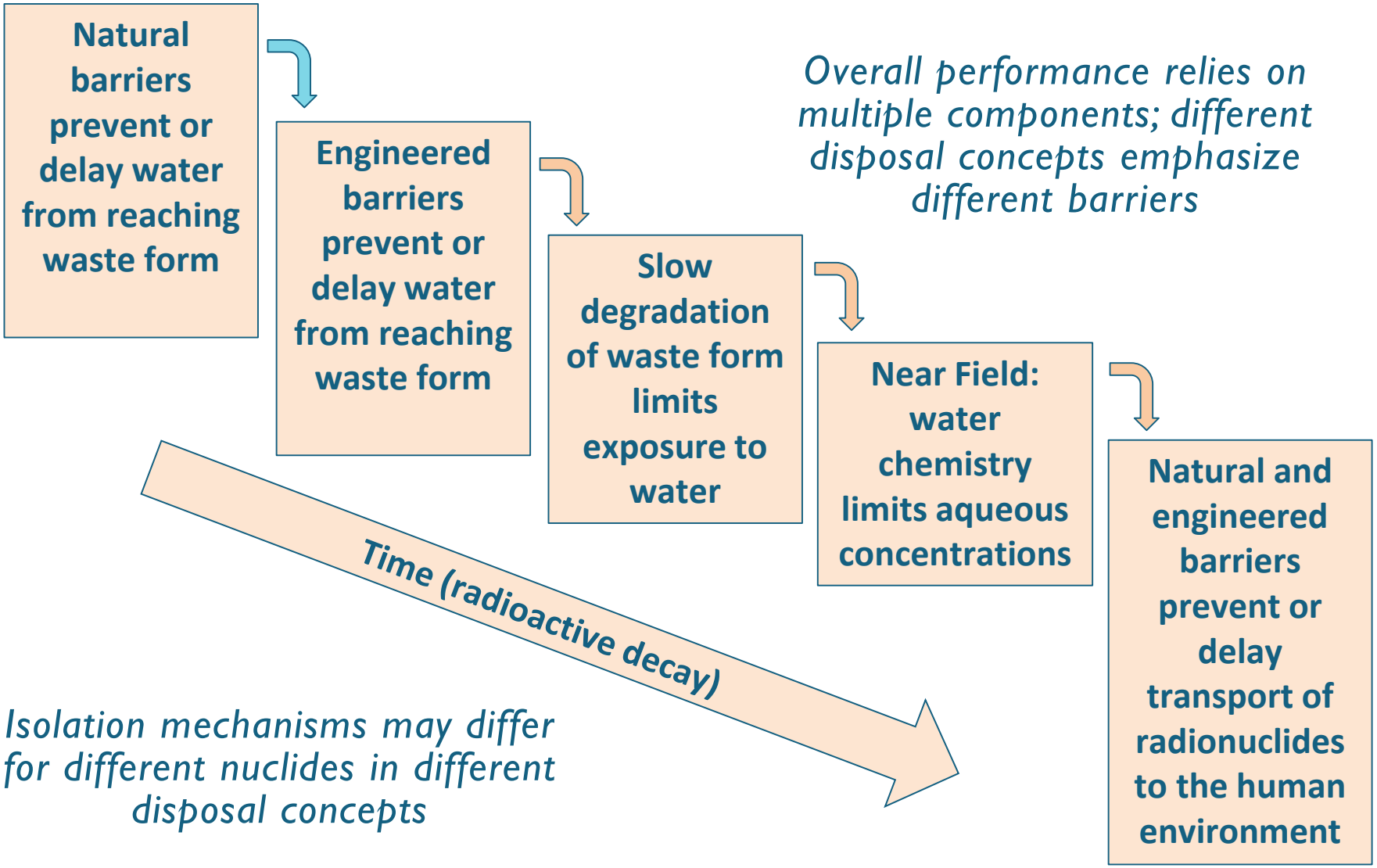


Source: Marcinowski, F., "Overview of DOE's Spent Nuclear Fuel and High-Level Waste," presentation to the Blue Ribbon Commission on America's Nuclear Future, March 25, 2010, Washington DC.

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 Deep Geologic Repositories Work

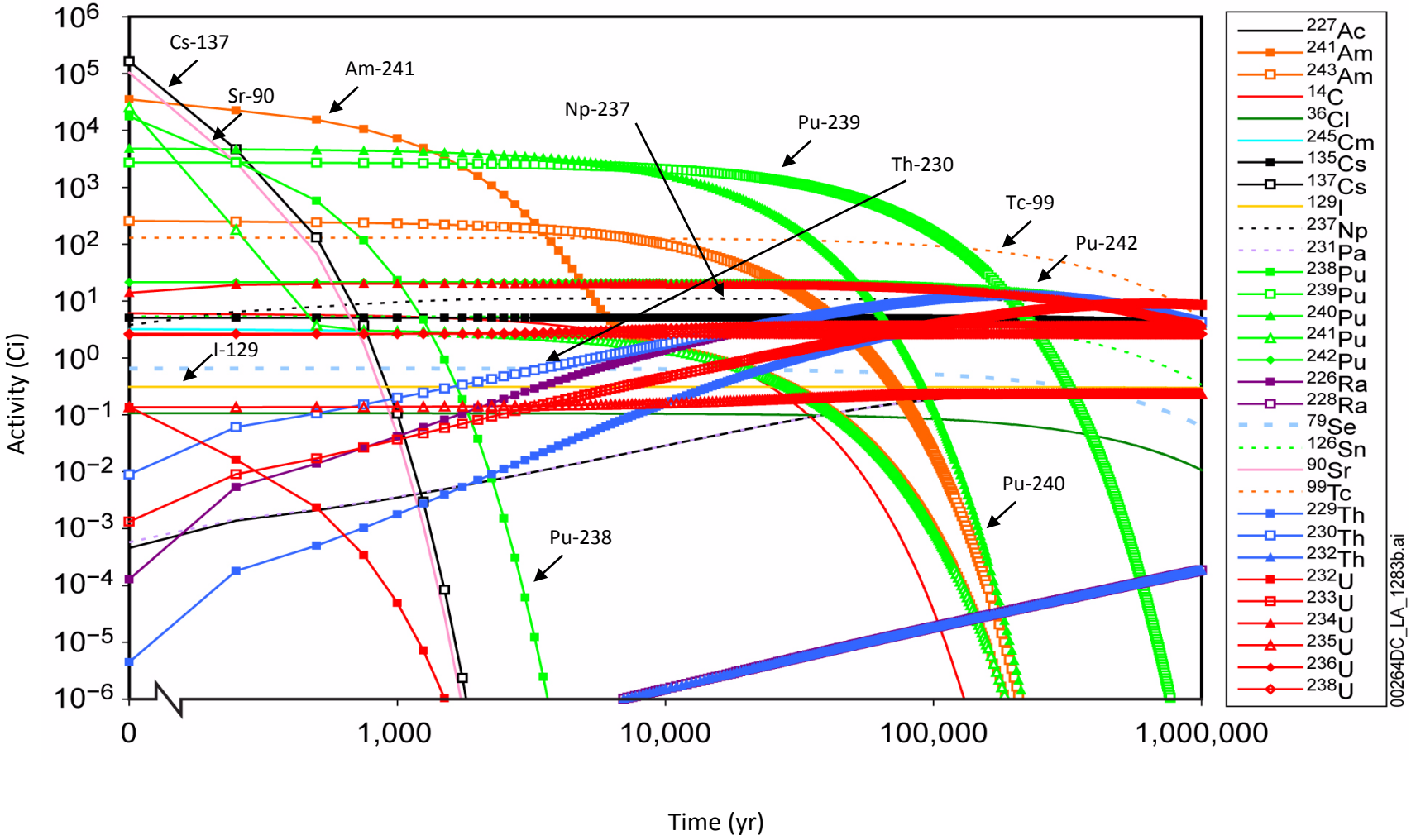


Overall performance relies on multiple components; different disposal concepts emphasize different barriers

Isolation mechanisms may differ for different nuclides in different disposal concepts

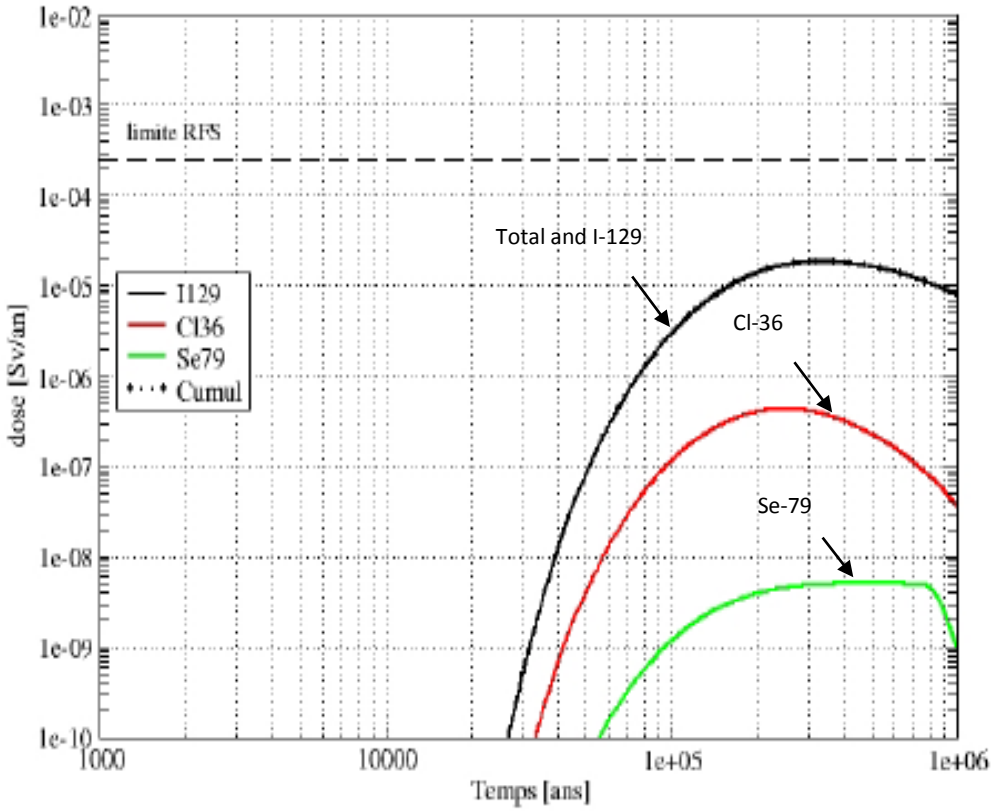
Light-Water Reactor Spent Nuclear Fuel Decay

Example from US Program



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)

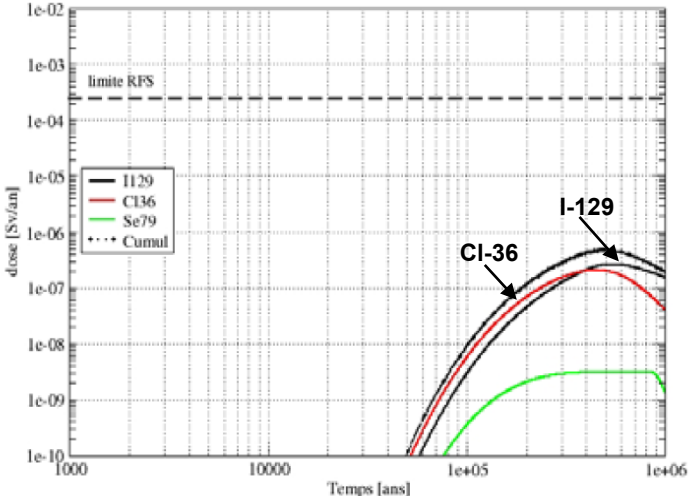


ANDRA 2005, *Dossier 2005: Argile. Tome: Evaluation of the Feasibility of a Geological Repository in an Argillaceous Formation*, Figure 5.5-18, million year model for spent nuclear fuel disposal and Figure 5.5-22, million year model for vitrified waste disposal

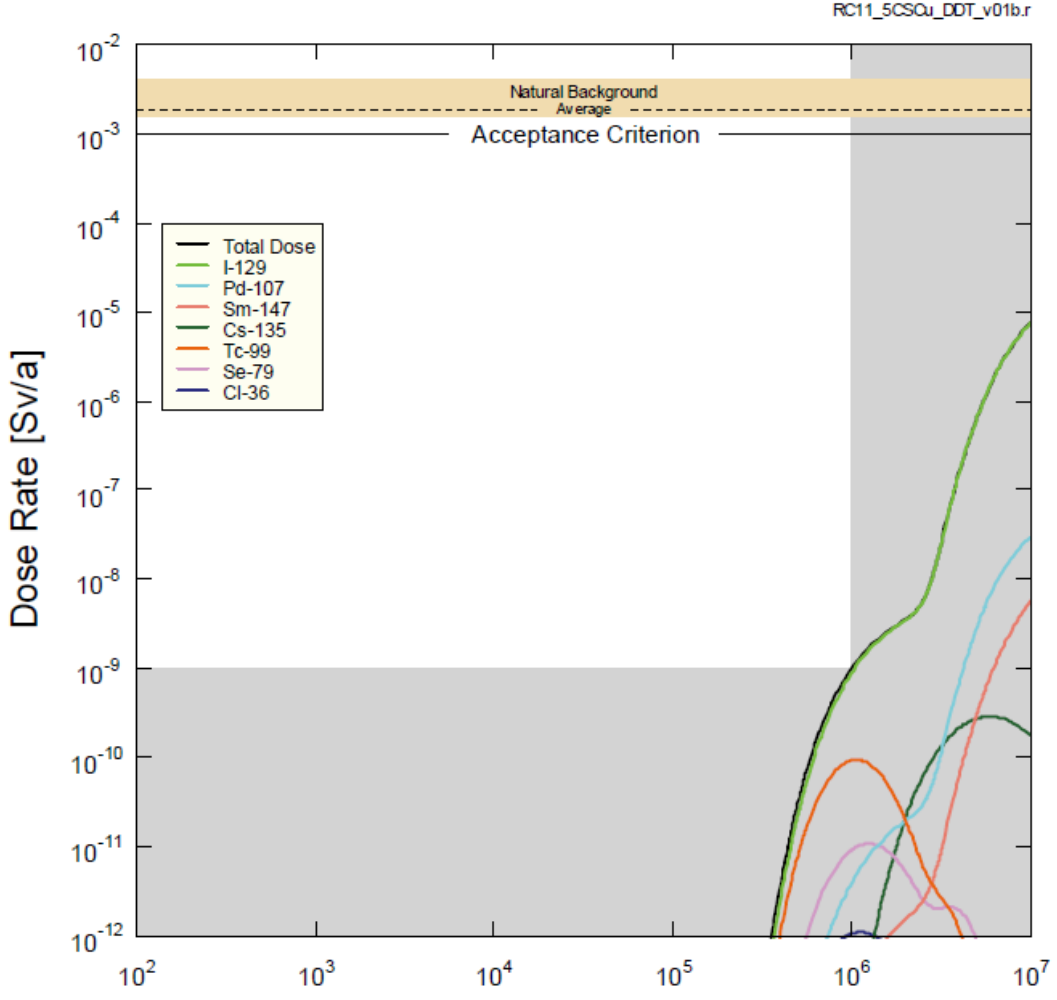
Diffusion-dominated disposal concept: Argillite

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, 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)

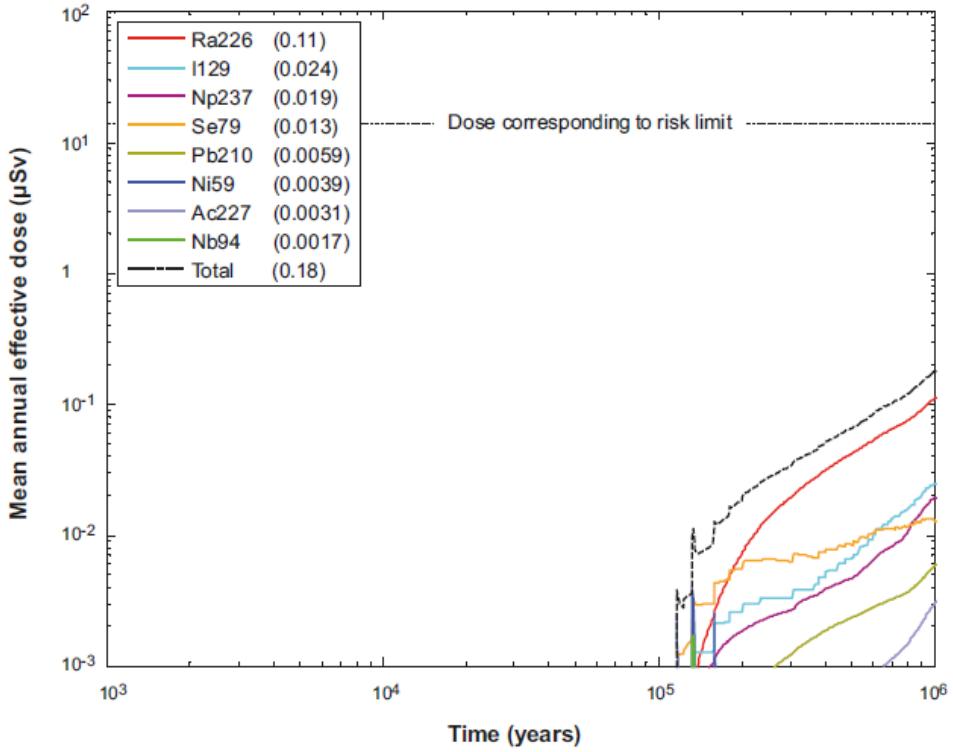


Figure 13-18. Far-field mean annual effective dose for the same case as in Figure 13-17. The legends are sorted according to descending peak mean annual effective dose over one million years (given in brackets in μSv).

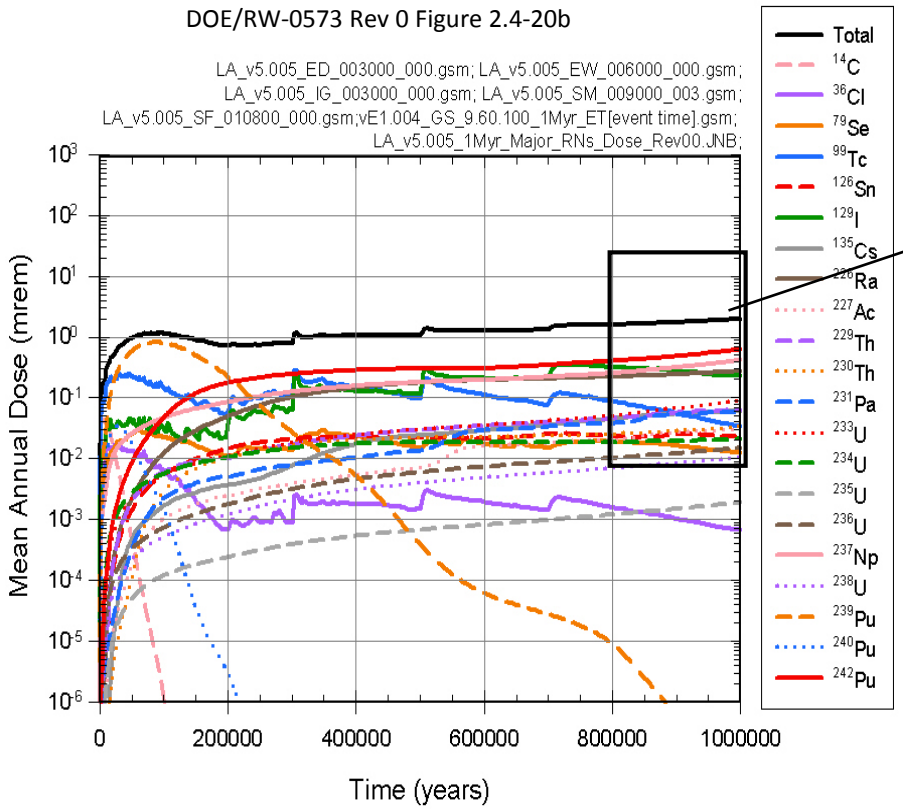
SKB 2011, Long-term safety for the final repository for spent nuclear fuel at Forsmark, Technical Report TR-11-01

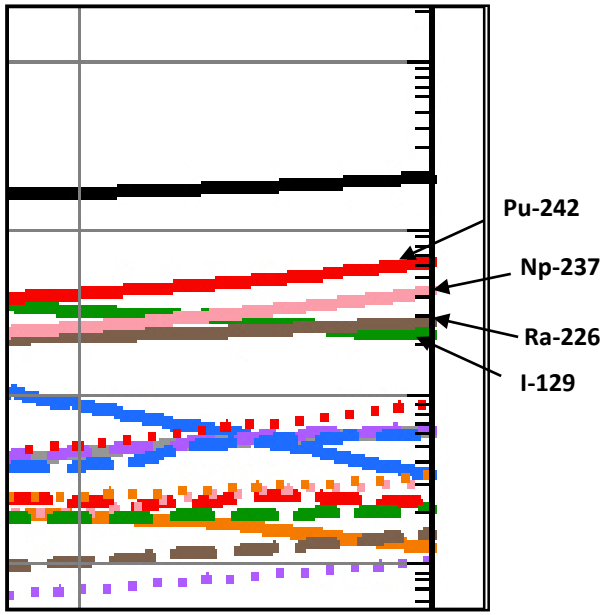
Disposal concept with advective fracture transport in the far-field: Granite

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. 1/10th of total

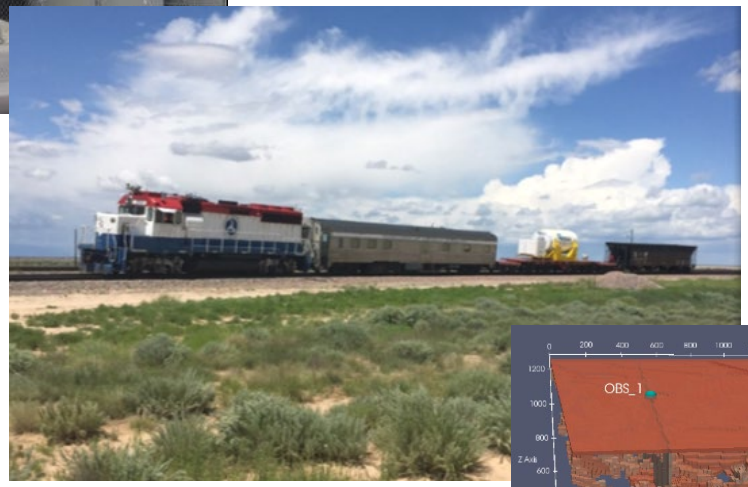
Summary and Conclusions

- 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 and continues to increase
  - 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

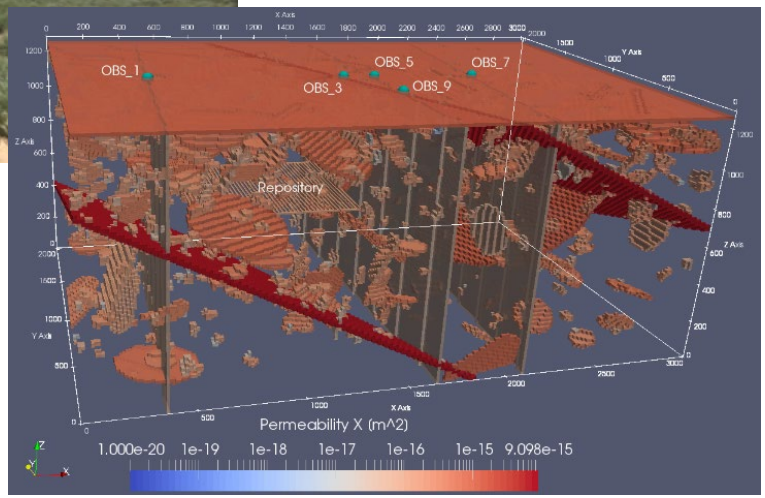
Backup Materials and References

U.S. DOE Office of Nuclear Energy
Spent Fuel & Waste Science & Technology (SFWST) R&D Campaign

Storage



Transportation



Disposal

SFWST R&D – Key Participants

- Managed by the US DOE NE Office of Spent Fuel and Waste Science and Technology (SFWST)
- Formerly referred to as the "Used Fuel Disposition" Campaign
- Nine national laboratories support the campaign

Argonne NATIONAL LABORATORY

BERKELEY LAB

INL Idaho National Laboratory

Science in the National Interest
Lawrence Livermore National Laboratory

Los Alamos NATIONAL LABORATORY

ornl OAK RIDGE NATIONAL LABORATORY

Pacific Northwest NATIONAL LABORATORY

Sandia National Laboratories

SRNL SAVANNAH RIVER NATIONAL LABORATORY

SFWST Strategic Focus: Storage and Transportation R&D

Prepare for extended storage and eventual large-scale transport of spent nuclear fuel and high-level waste

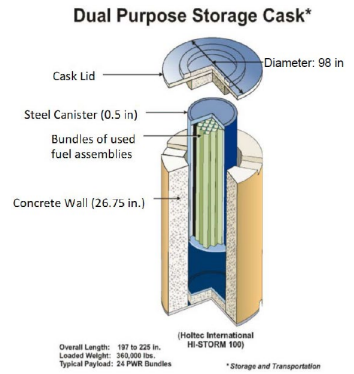
- Support the technical basis for evaluating:
  - Extended storage of spent nuclear fuel
  - Fuel retrievability and transportation after extended storage
  - Transportation of high-burnup spent nuclear fuel

Major Activities - Storage and Transportation R&D

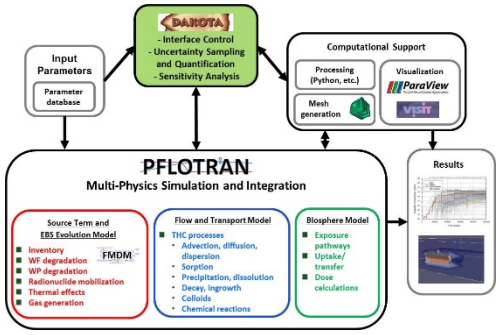
- High burnup fuel testing to support storage demonstration project
  - Non-destructive testing is complete
  - ORNL and PNNL are starting destructive testing
  - ANL has received samples and will test soon
- Corrosion
  - Improved understanding of salt deposition and decomposition rates, incubation times, pitting progression, and crack initiation and growth rates
  - Crack consequence experimental work and modeling has begun
  - Initiated repair and mitigation studies
- Transportation Handling Tests
  - Completion of 30 cm drop test; analyses of stress on fuel in progress
  - Designing a 9 m drop to get data on viability of pinch loads
- Residual Water After Drying
  - Analyzed gas samples from storage demonstration test and working to get more gas samples
  - Planning for experimental set up
  - Initiated consequence analysis
- Thermal Work
  - Vertical BWR experiments complete and horizontal test set up has begun
  - Blind round-robin modeling will continue

Major Activities - Disposal R&D

- Argillite, Crystalline, and Salt Research
  - Experimental data and modeling of bentonite performance at elevated temperatures
  - Improved techniques for modeling fracture flow and transport
  - Borehole heater test in progress at WIPP
- Options for Dual Purpose Canisters
  - Continue analysis of potential for post closure criticality
    - Conduct post closure criticality consequence analysis
    - Analyses of DPC fillers for criticality control
    - Modeling of DPC post closure performance including fillers
    - Design enhancement options for existing and future DPCs
  - Geotechnical considerations for post closure performance
- Geological Disposal Safety Assessment (GDSA)
  - High performance computing of system performance (PFLOTRAN)
  - Uncertainty Quantification and Sensitivity Analysis tools
  - Performance assessment inventory of DOE-managed wastes
- Enhanced R&D and International Collaborations to support concepts in multiple geologic media



Example of a dual-purpose canister inside a storage overpack (cask) (modified from Easton 2011).



SFWST: International Portfolio with URL Focus

Multinational Initiatives

Mont Terri Project
- Participate in experiments at Mont Terri clay URL in Switzerland

DECOVALEX Project
- Participate in model comparison initiative for several URLs related tasks in different host rocks

Colloid Formation & Migration Project
- Participate in colloid research at Grimsel granite URL in Switzerland (SFWST participation ended in 2015)

FEBEX DP
- Participate in FEBEX dismantling project, which evaluates bentonite-rock behavior after 18 years of heating

SKB Task Forces
- Participate in crystalline rock research centered around Äspö HRL in Sweden

HotBENT (starting soon)
- Conduct a high-temperature heater test to evaluate feasibility of 200°C waste disposal

Bilateral Research Collaborations

US-Republic of Korea (ROK)
- Participate in KAERI Underground Research Tunnel (KURT) experiments in crystalline rock
- High Level Bilateral Commission (HLBC), information exchange in used fuel disposal

US-Germany Salt Collaboration
- Participate in testing and modeling studies for thermal-mechanical and hydrological behavior of domal and bedded salt

US-Sweden COSC Collaboration
- Participate in testing hydrogeological characterization methods

There are several other international collaboration activities not focused on URL access and participation, e.g., the Thermodynamic Database Project, or NEA's Clay, Salt and Crystalline Clubs.

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