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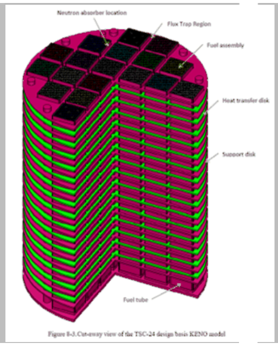

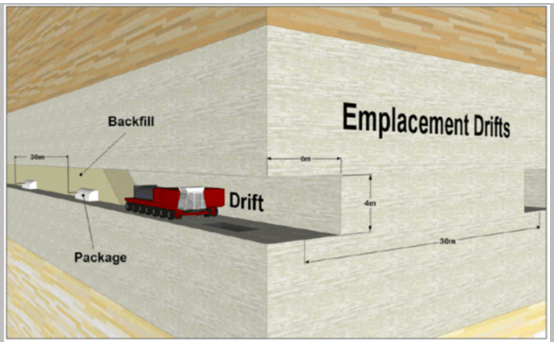

A1 + A2: Overview of Radioactive Waste Management and Geologic Disposal R&D in the U.S.

Ernest Hardin

December, 2014

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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Acknowledgements

Based on input and previous presentations developed by Peter Swift, Bob MacKinnon, John Cochran, Elena Kalinina, John Wagner, Ken Picha, and many others.

Outline

- **Radioactive Waste Management in the U.S.**
  - Classification and Implementor/Regulator Responsibilities
  - Example Types
  - Disposal Pathways
- **Used Fuel Disposition R&D in the U.S.**
  - Current Generic Program
  - Storage and Transportation Emphasis
  - Direct Disposal of Dual-Purpose (Storage-Transportation) Canisters
  - Status of Yucca Mountain

Waste Classification and Disposition Pathways in the U.S.

Defense vs. Commercial

Different Regulators

High-Level Waste (HLW) and Spent Nuclear Fuel (SNF)

Low-Level Waste (LLW) and Defense Low-Activity Waste (LAW)

Greater-than-Class-C LLW or Defense "GTCC-Like" Waste

Transuranic (TRU) Defense Waste

Defense Waste Incidental to Reprocessing (WIR)

Nuclear Waste Classification in the U.S.

High-Level Waste (HLW) and Spent Nuclear Fuel (SNF)

Defense HLW and SNF (extensive reprocessing)

Commercial HLW and SNF (limited reprocessing)

Low-Level Waste (LLW)

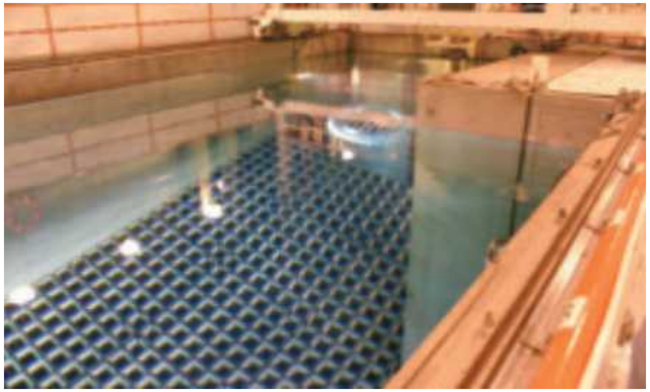
Defense low-activity waste (LAW)

Commercial LLW (Class A, B and C)

Greater-than-Class-C LLW or "GTCC-like" defense waste

Transuranic (TRU) waste (defense; mainly Am & Pu)

Waste Incidental to Reprocessing (WIR; defense)



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Legend

★ Commercial sites

Note: The Repository SEIS analysis considers three commercial site pairs — Salem and Hope Creek (NJ), Nine Mile Point and FitzPatrick (NY), and Dresden and Morris (IL) — to be single sites due to their proximity to each other.

◉ DOE sites

Note: The Repository SEIS analysis includes the high-level radioactive waste at West Valley. The State of New York owns the high-level radioactive waste and the site. Under the *West Valley Demonstration Project Act*, DOE is responsible for solidifying and transporting the high-level radioactive waste to a repository.

Note: The Yucca Mountain FEIS analysis included DOE spent nuclear fuel at Fort St. Vrain in Colorado. DOE will move that spent nuclear fuel to the Idaho National Laboratory for packaging and it would be included in the laboratory inventory. Therefore, this map does not show Fort St. Vrain as a DOE source of spent nuclear fuel.

Commercial Nuclear Power Plants and DOE Cleanup Sites: Major sources for LWW, GTCC and SNF/HLW

Nuclear Waste Classification in the U.S. – HLW & SNF

High-Level Waste (HLW) and Spent Nuclear Fuel (SNF)

Defense (extensive) AND Commercial (limited) HLW + SNF

A. Regulators: U.S. NRC and EPA + Individual States

B. Disposal pathway: Deep geologic disposal

C. Examples:
* Commercial and defense SNF
* HLW glass (Savannah River, West Valley, Idaho, Hanford)
* Calcined waste and sodium-bearing waste (Idaho)
* Cs-Sr capsules (Hanford)

Low-Level Waste (LLW)

Defense low-activity waste (LAW)

Commercial LLW (Class A, B and C)

Greater-than-Class-C LLW or GTCC-like defense waste

Commercial GTCC

Defense "GTCC like"

Transuranic (TRU) waste (defense; mainly Am & Pu)

Waste Incidental to Reprocessing (WIR; defense)

Nuclear Waste Classification in the U.S. – Defense LAW/LLW

High-Level Waste (HLW) and Spent Nuclear Fuel (SNF)

Defense HLW and SNF (extensive reprocessing)

Commercial HLW and SNF (limited reprocessing)

Low-Level Waste (LLW)

Defense low-activity waste (LAW) and LLW

A. **Regulators:** U.S. DOE (implementor and regulator) + Individual States

B. **Disposal pathways:**
* Convert liquid LAW to solid LLW
* Saltstone (Savannah River Site)
* Vitrified waste form (Hanford)

C. **Examples:**
* LAW liquid from tank waste
* Facility operations and decommissioning

Commercial LLW (Class A, B and C)

Greater-than-Class-C LLW or GTCC-like defense waste

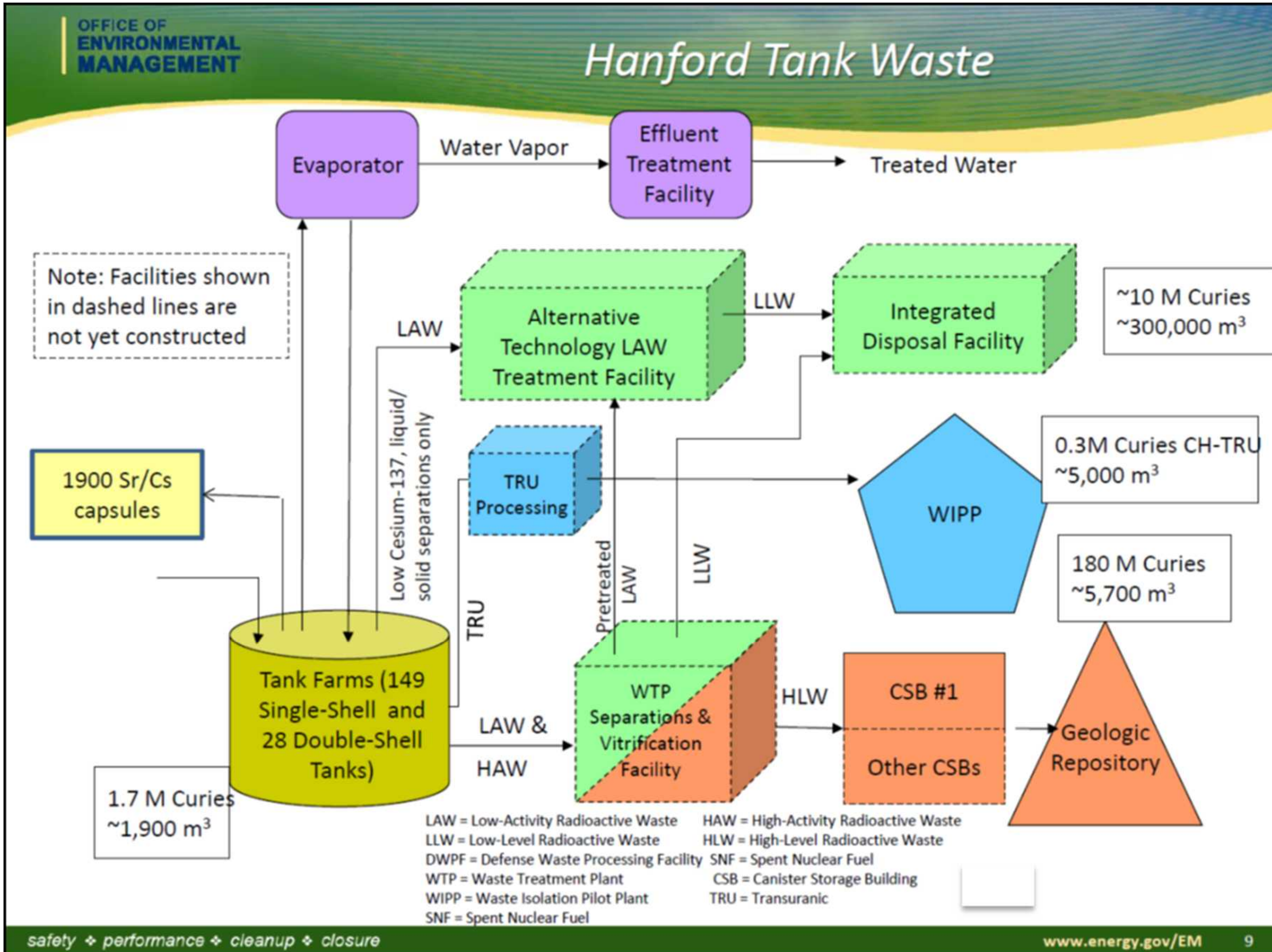
Commercial GTCC

Defense "GTCC like"

Transuranic (TRU) waste (defense; mainly Am & Pu)

Waste Incidental to Reprocessing (WIR; defense)

LAW/HLW Separates from Tank Waste



Slide from: Picha, K. 2013. *Nuclear Waste Technical Review Board Overview: Office of Environmental Management*. Presentation April 16, 2013. (www.nwtrb.gov)

Nuclear Waste Classification in the U.S. – LLW

High-Level Waste (HLW) and Spent Nuclear Fuel (SNF)

Defense HLW and SNF (extensive reprocessing)

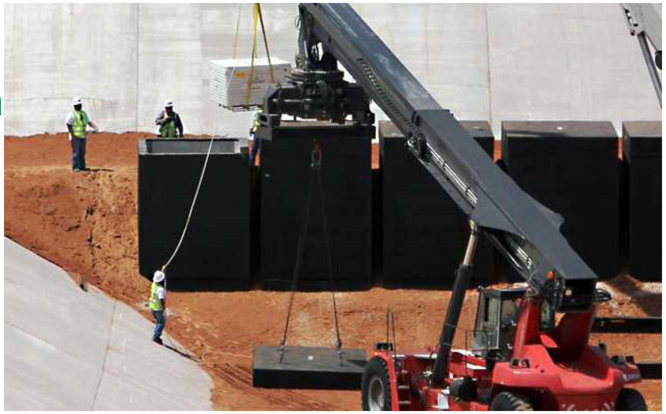
Commercial HLW and SNF (limited reprocessing)

Low-Level Waste (LLW)

Defense low-activity waste (LAW)

Commercial LLW (Class A, B and C)

- **A. Regulators:** **U.S. NRC and EPA + Individual States**
- **B. Disposal pathway:** **Near-surface burial**
- **C. Examples:** *** Nuclear power plant operatin and decommissioning**
  *** Research, industrial, and medical LLW**



Greater-than-Class-C LLW or GTCC-like defense waste

Commercial GTCC

Defense "GTCC like"

Transuranic (TRU) waste (defense; mainly Am & Pu)

Waste Incidental to Reprocessing (WIR; defense)

Nuclear Waste Classification in the U.S. – GTCC

High-Level Waste (HLW) and Spent Nuclear Fuel (SNF)

- Defense HLW and SNF (extensive reprocessing)
- Commercial HLW and SNF (limited reprocessing)

Low-Level Waste (LLW)

- Defense low-activity waste (LAW)
- Commercial LLW (Class A, B and C)

Greater-than-Class-C LLW or "GTCC-like" defense waste [A]

A. **Regulators:** **U.S. NRC and EPA + Individual States**

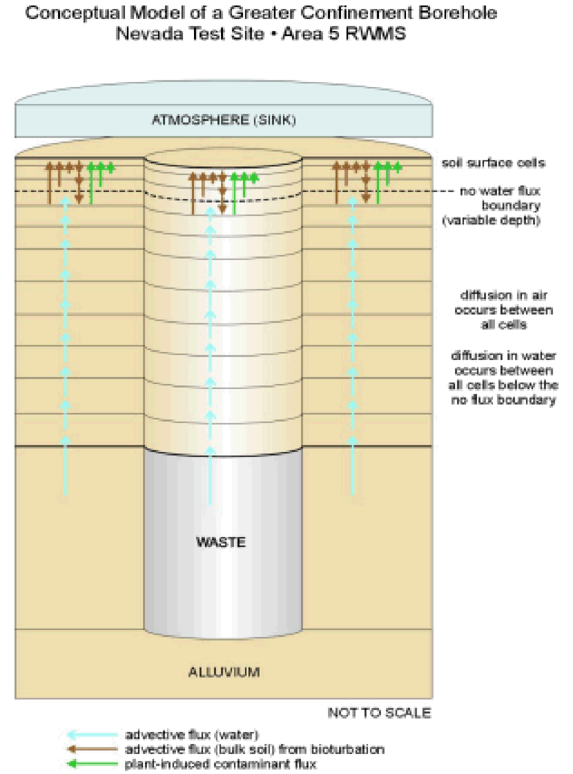
B. **Disposal pathways:**
- *** Deep greater confinement disposal**
- *** Geologic co-disposal**

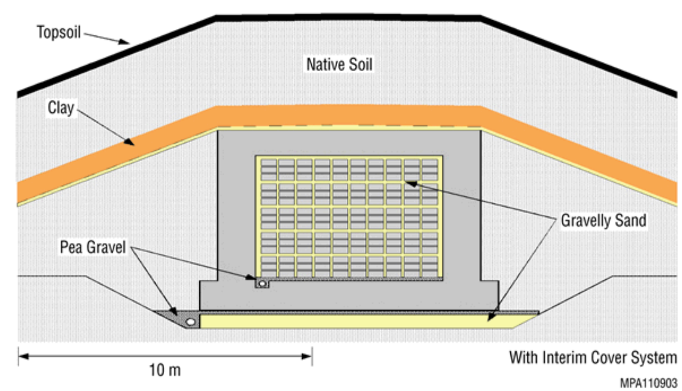
C. **Examples:**
- *** Activated metals**
- *** Sealed sources**

Transuranic (TRU) waste (defense; mainly Am & Pu)

Waste Incidental to Reprocessing (WIR; defense)

[A] "GTCC like" is commonly used for defense waste that does not meet LLW criteria or result directly from reprocessing, but it is not a formal waste classification.





Nuclear Waste Classification in the U.S. – TRU

High-Level Waste (HLW) and Spent Nuclear Fuel (SNF)

- Defense HLW and SNF (extensive reprocessing)
- Commercial HLW and SNF (limited reprocessing)

Low-Level Waste (LLW)

- Defense low-activity waste (LAW)
- Commercial LLW (Class A, B and C)

Greater-than-Class-C LLW or “GTCC-like” defense waste

- Commercial GTCC
- Defense “GTCC like”

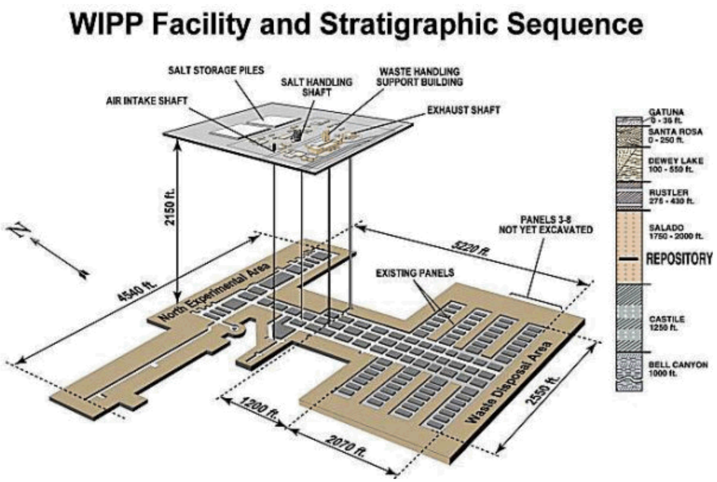
Transuranic (TRU) waste (defense; mainly Am & Pu)

A. **Regulators:** **U.S. EPA only (WIPP) + Individual States**

B. **Disposal pathways:** *** Deep geologic disposal (WIPP)**
*** On-site disposal solutions under study**

C. **Example:** **Material processing and facility decommissioning**

Waste Incidental to Reprocessing (WIR; defense)



Nuclear Waste Classification in the U.S. – WIR

High-Level Waste (HLW) and Spent Nuclear Fuel (SNF)

Defense HLW and SNF (extensive reprocessing)

Commercial HLW and SNF (limited reprocessing)

Low-Level Waste (LLW)

Defense low-activity waste (LAW)

Commercial LLW (Class A, B and C)

Greater-than-Class-C LLW or “GTCC-like” defense waste

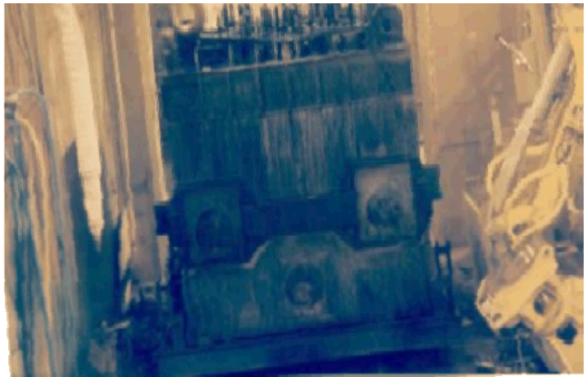
Commercial GTCC

Defense “GTCC like”

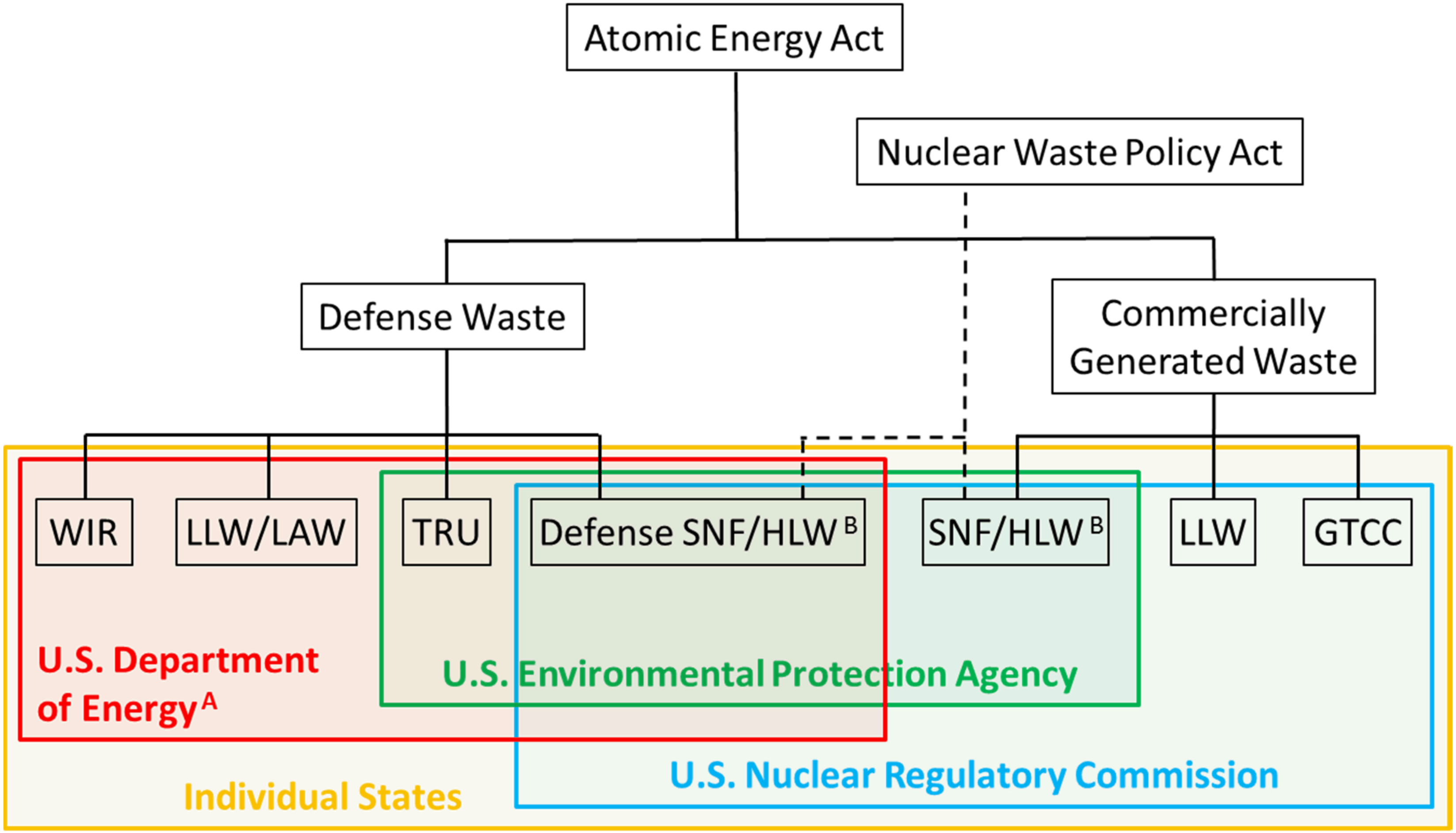
Transuranic (TRU) waste (defense; mainly Am & Pu)

Waste Incidental to Reprocessing (WIR; defense)

- **A. Regulators:** **U.S. DOE (possible NRC oversight) + Individual States**
- **B. Disposal pathway:** **Dispose as LLW or TRU, or by on-site immobilization**
- **C. Examples:** *** Grouted tank residues**
  *** Tank salt solutions converted to solid form (e.g., saltstone, vitrified, or carbonate)**



Summary of Radioactive Waste Management Classification and Responsibility in the U.S.



[A] The U.S. DOE is both implementor and regulator for WIR, LLW and TRU (except at WIPP), with potential oversight from the U.S. NRC, and direct involvement of the NRC for SNF and HLW.

[B] U.S. DOE is implementor for all SNF and HLW (including commercial HLW at West Valley, NY).

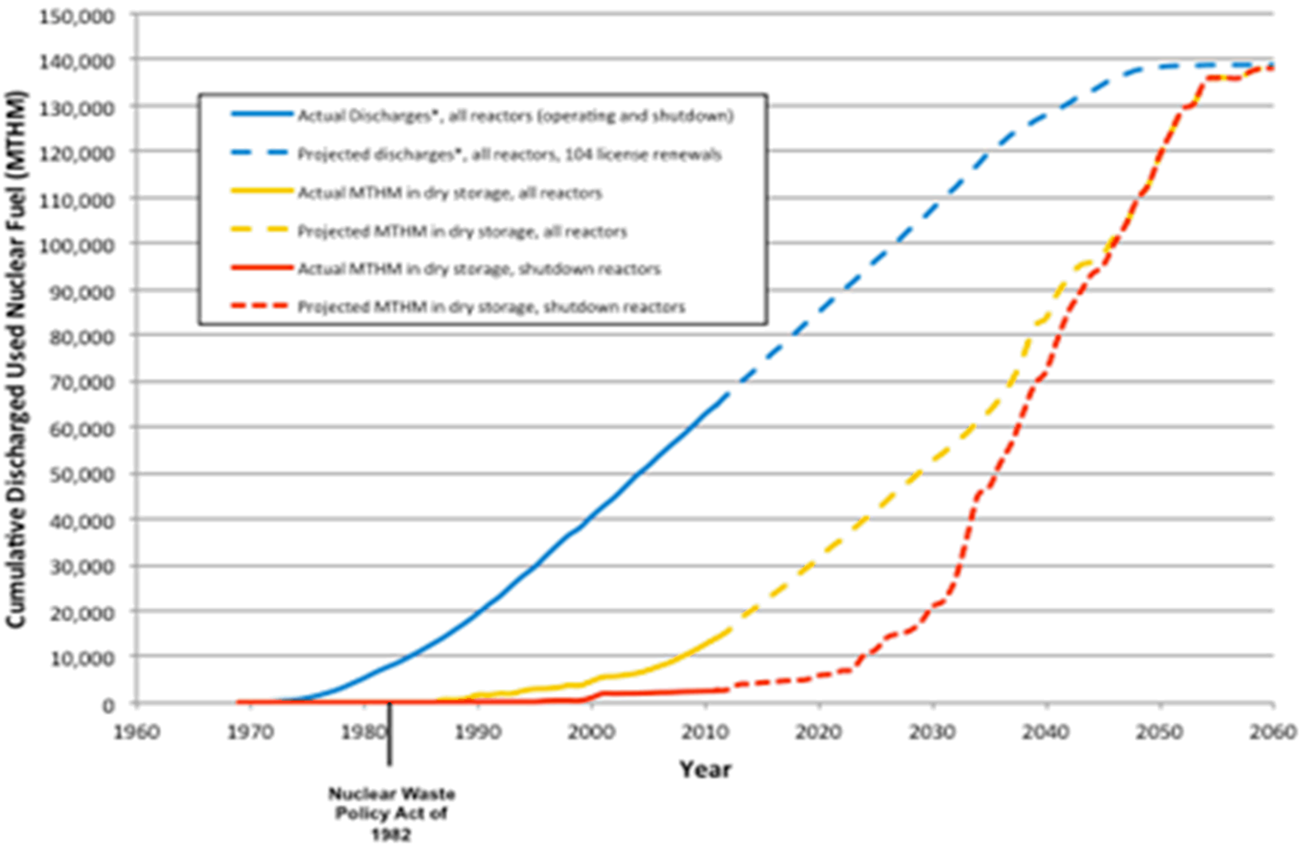
Commercial-Scale Reprocessing in the U.S.?

Projected SNF Quantities from Existing Power Plants

Thermal- vs. Fast-Reactor Strategies for Pu-Recycle

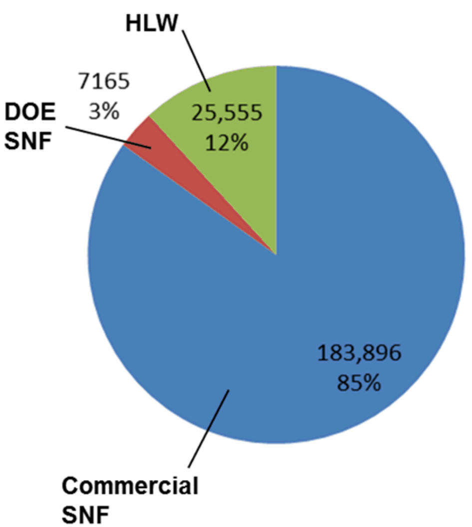
How Much Light-Water Reactor (LWR) SNF is Needed for a Future Transition?

Projections of Future SNF and HLW for Geologic Disposal



Source: *Based on actual discharge data as reported on RW-859s through 12/31/02, and projected discharges, in this case for 104 license renewals

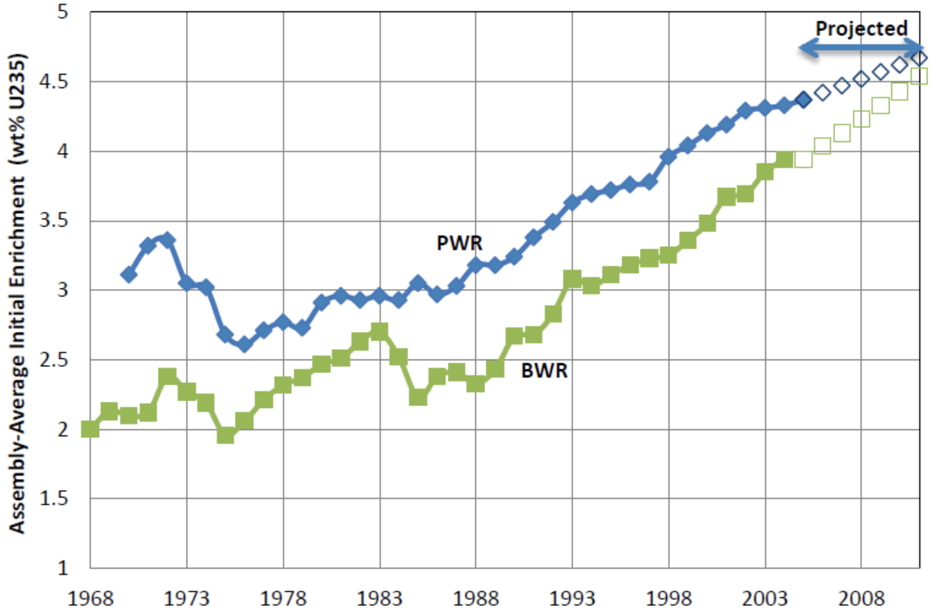
Projected Volumes of SNF and HLW in 2048



Volumes shown in m^3, assuming constant rate of nuclear power generation

Historical and Projected Commercial SNF Discharges in the United States

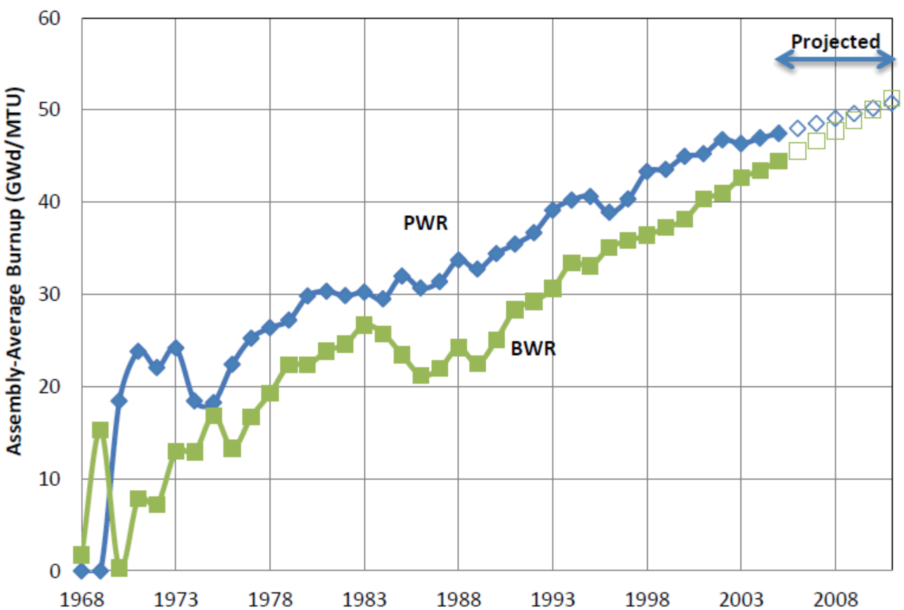
Trends in Commercial Spent Fuel Burnup and Enrichment



← Assembly-average initial fuel enrichment ($^{235}U/^{238}U$)

↓ Assembly-average burnup (GW-d/MT)

Source: Wagner et al. 2012. Categorization of Used Nuclear Fuel Inventory in Support of a Comprehensive National Nuclear Fuel Cycle Strategy. FCRD-FCT-2012-000232. U.S. Department of Energy, Office of Used Nuclear Fuel Disposition.

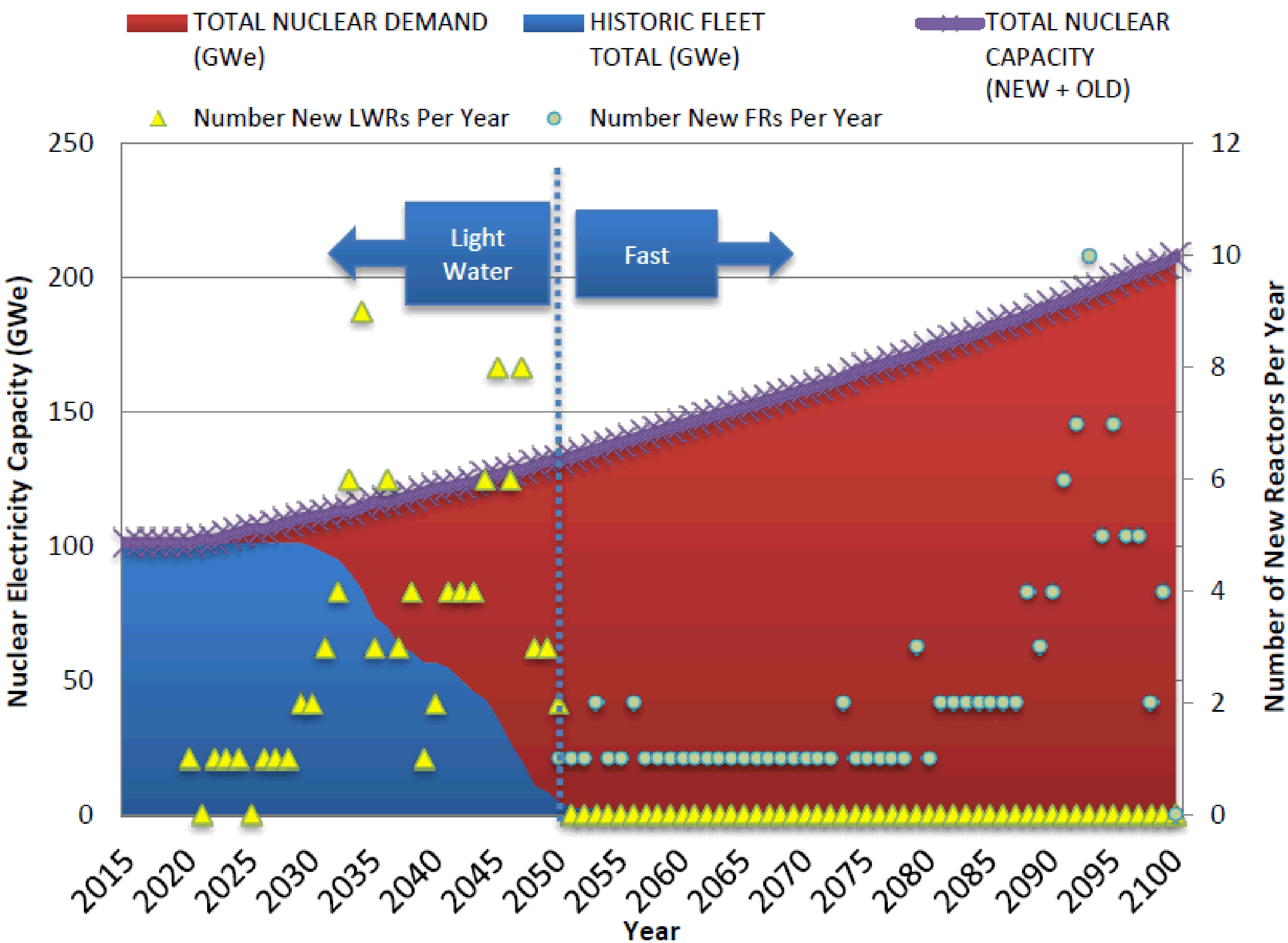


Future Fuel Cycle Considerations

- **MOX thermal-reactor Pu-recycle considerations**
  - **Non-fissile Pu in-growth during irradiation (^{240}Pu, ^{242}Pu)**
  - **Loss of ^{241}Pu (→ ^{241}Am, $t_{1/2}$ 14.4 yr)**
  - **Favors younger, higher-burnup SNF (existing U.S. inventory is older, low-burnup)**
  - **Refit/redesign of most U.S. commercial reactors for large-scale MOX implementation**
- **Fast-reactors or fast/thermal combined considerations**
  - **Favorable energy yield and waste minimization**
  - **Technology available and understood (compared to other options)**
  - **Most promising future fuel cycles ***

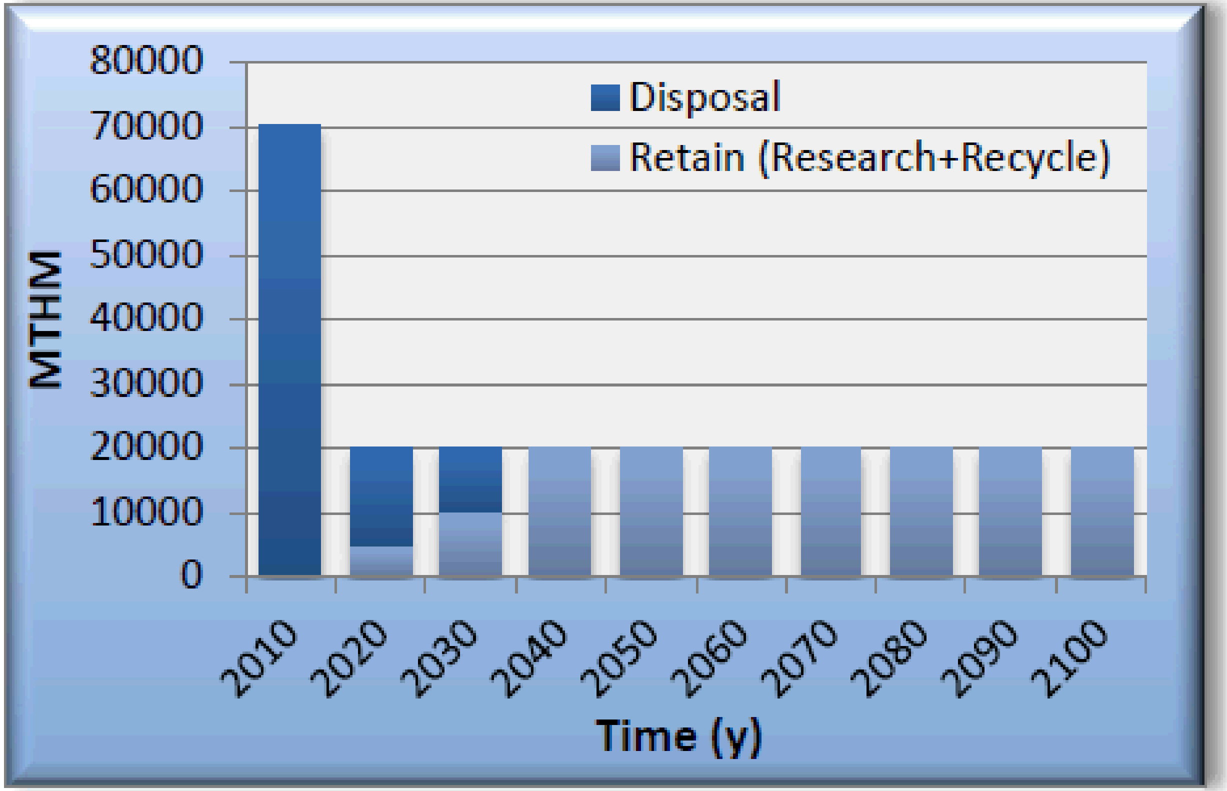
* Wigeland et al. 2014. *Nuclear Fuel Cycle Evaluation and Screening – Final Report*. FCRD-FCO-2014-000106. U.S. Department of Energy, Office of Fuel Cycle Technology R&D.

Projected Future Thermal- and Fast-Reactor Builds in the U.S.



Source: Wagner et al. 2012. Categorization of Used Nuclear Fuel Inventory in Support of a Comprehensive National Nuclear Fuel Cycle Strategy. FCRD-FCT-2012-000232. U.S. Department of Energy, Office of Used Nuclear Fuel Disposition.

How much LWR fuel is needed to initiate a future, fully closed fuel cycle?



→ Geologic disposal of ≥~95,000 MTU LWR SNF

Source: Wagner et al. 2012. Categorization of Used Nuclear Fuel Inventory in Support of a Comprehensive National Nuclear Fuel Cycle Strategy. FCRD-FCT-2012-000232. U.S. Department of Energy, Office of Used Nuclear Fuel Disposition.

Geologic Disposal R&D in the U.S.

Current Generic Program

Status of Yucca Mountain

Storage and Transportation Emphasis

Geologic Disposal R&D in the U.S.

Current Generic Program

Status of Yucca Mountain

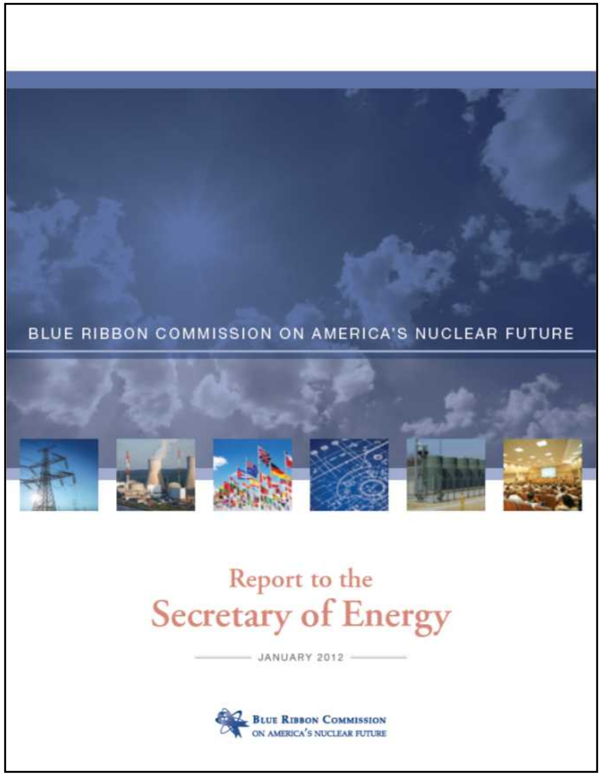
Storage and Transportation Emphasis

"Blue Ribbon" Commission on America's Nuclear Future

Convened at the request of President Obama in 2009.

Eight Recommendations

1. New, consent-based approach to siting
2. New implementor organization
3. Full access to nuclear waste trust fund
4. Prompt efforts to develop geologic disposal facility(s)
5. Prompt efforts to develop consolidated storage facility(s)
6. Prepare for large-scale transport of SNF/HLW
7. Support for U.S. innovation in nuclear energy technology and workforce development
8. Active U.S. participation in international efforts (safety, waste management, non-proliferation, security)



Status of Yucca Mountain License Application viz. BRC Recommendations

1. **New, consent-based approach to siting**

   Yucca Mountain selection and licensing process was adversarial.

2. **New implementor organization**

   Independence could make future repository implementation more stable.

3. **Full access to nuclear waste trust fund**

   From 1983 – 2009 funds were voted annually by the U.S. Congress.

4. **Prompt efforts to develop geologic disposal facility(s)**

   The Yucca Mountain project was delayed ~20 years (repository opening delayed 1998 → 2017+)

5. **Prompt efforts to develop consolidated storage facility(s)**

   Implementing centralized surface storage is linked to repository siting and construction, and cannot be legally started until the Nuclear Waste Policy Act is changed.

6. **Prepare for large-scale transport of SNF/HLW**

   Already a priority for the Yucca Mountain Project, this work is ongoing.

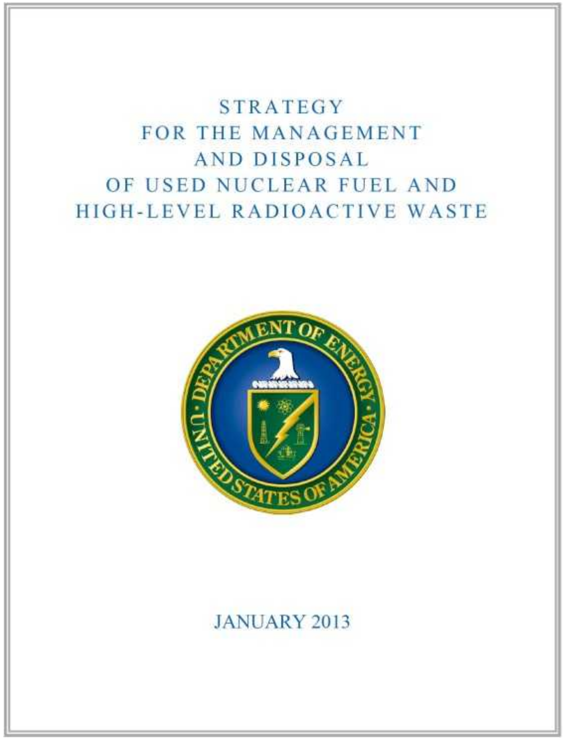
Summary of Current U.S. Strategy for Used Nuclear Fuel and High-Level Radioactive Waste

The document: *Strategy for the Management and Disposal of Used Nuclear Fuel and High-Level Radioactive Waste*. January, 2013.

- A statement of Administration policy regarding the importance of addressing the disposition of used nuclear fuel (UNF) and high-level radioactive waste (HLW)
- The Response to the final report and recommendations made by the *Blue Ribbon Commission on America's Nuclear Future*
- The initial basis for discussions among the Administration, Congress and other stakeholders

A 10+ year program:

- Site, design, license, construct and begin operation of a pilot SNF storage facility (**operating 2021**)
- Advance toward siting and licensing of a larger centralized SNF storage facility (**operating 2025**)
- Make demonstrable progress on siting and characterization for geologic disposal (**sited 2026, operating 2048**)


STRATEGY
FOR THE MANAGEMENT
AND DISPOSAL
OF USED NUCLEAR FUEL AND
HIGH-LEVEL RADIOACTIVE WASTE

JANUARY 2013

DOE's R&D Program for Used Nuclear Fuel Disposition (Storage, Transportation and Disposal)

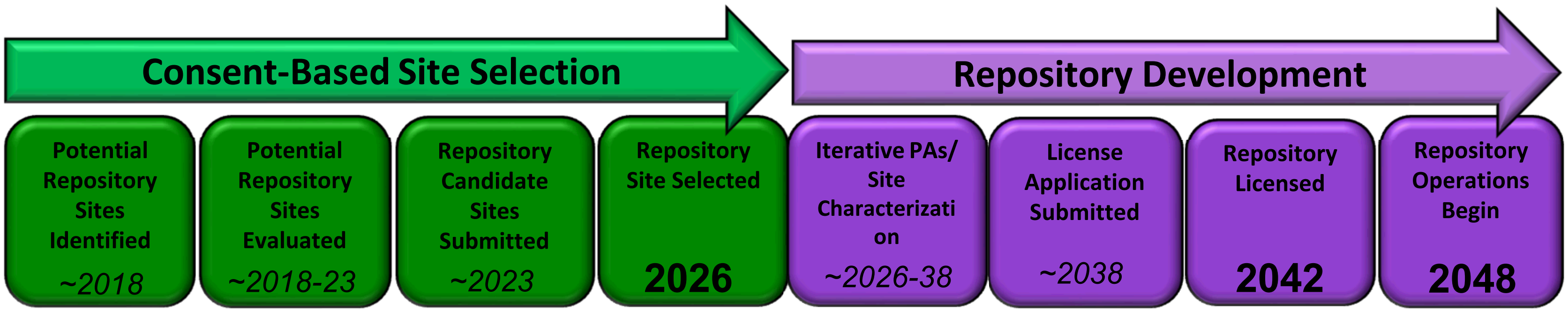
Nine national laboratories participate in the DOE Office of Nuclear Energy Used Fuel Disposition R&D Campaign:

Campaign Mission: to identify alternatives and conduct scientific research and technology development to enable storage, transportation and disposal of used nuclear fuel and wastes generated by existing and future nuclear fuel cycles.

R&D Path to Support DOE Waste Management Strategy

Storage & Transportation R&D

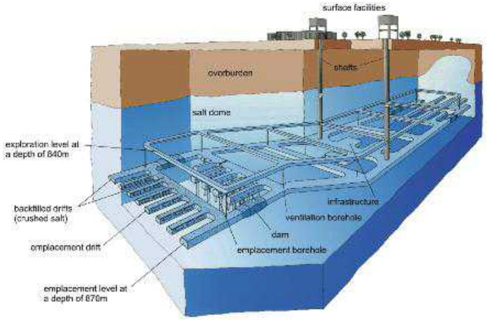
Disposal R&D



Approximate target dates (in *italics*) needed to meet deadlines (in **bold**) set out in the 2013 DOE strategy for disposition of commercial reactor spent fuel

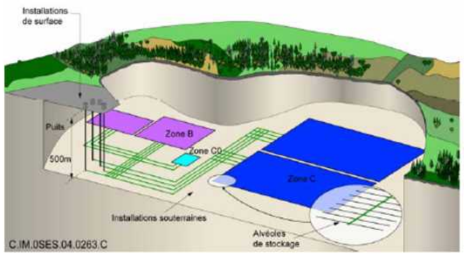
UFD Campaign Strategic Focus: Disposal R&D (2009 – present)

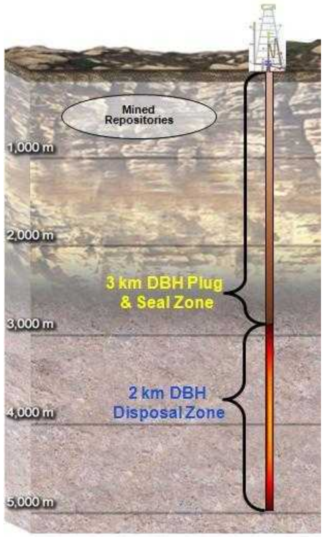
- **What can generic R&D accomplish?**
  - Sound technical basis for multiple viable disposal options in the US
  - Increased confidence in the robustness of generic concepts
  - Develop the science and engineering tools needed to support implementation



Salt concept (Gorleben)

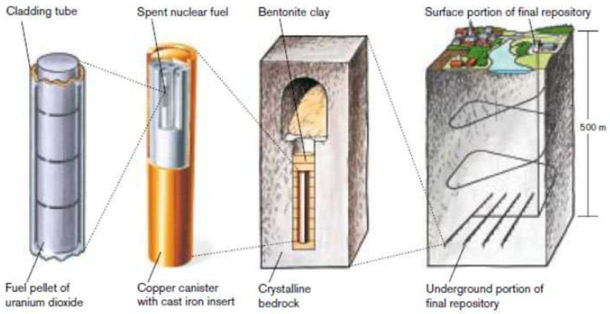
Argillaceous concept (ANDRA 2005)





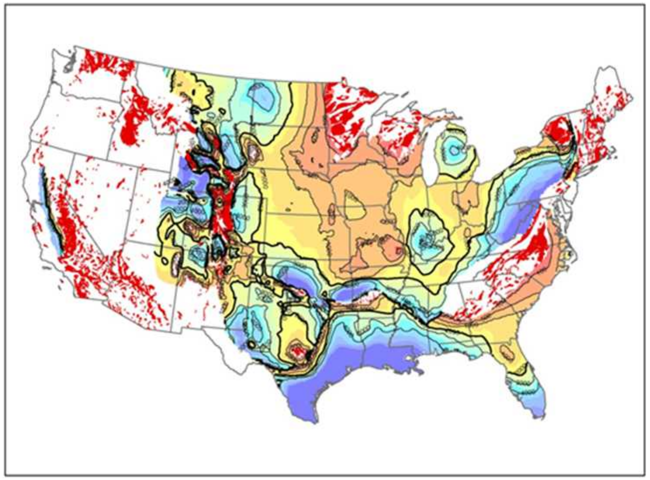
Deep borehole disposal concept

KBS-3 concept



Geologic Disposal R&D 2014 Activities

- **Generic Disposal Research Studies**
  - Argillaceous Media
  - Crystalline
  - Salt
  - Deep Borehole Disposal



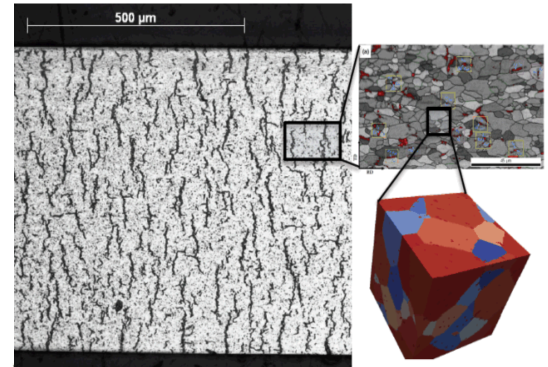
- **SNF Waste Form Degradation Model**
- **Waste Isolation System Safety Analysis (performance assessment)**
- **Regional Geology and Siting Geographic Information System**
- **Feasibility of Direct Disposal of Dual Purpose Canisters**
- **Concept Development for SNF and HLW Disposal**
- **International Collaborations**

UFD Campaign R&D Focus for Storage and Transportation

- **Prepare for extended storage (up to 100 years?)**
- **Prepare for eventual large-scale transport (after storage) of SNF and HLW**
- **Develop the technical basis for:**
  - Long-term changes in zirconium-alloy cladding
  - Dry-storage canister longevity
  - Transportation of high-burnup used nuclear fuel

Storage and Transportation R&D 2014 Activities

- **Experiments**
  - Fuel Clad Testing
  - Canister Stress Corrosion Cracking Investigations
- **Analysis**
  - Process-Coupled Simulation of Hydride Behavior and Cracking
  - Thermal Analyses of Dry Storage Systems In Situ
- **Transportation**
  - Simulate Fuel Assembly Shock and Vibration Testing
- **Field Demonstration**
  - Test Plan for Fuel Pin Recovery and Analysis



Disposability of Dual-Purpose Storage-Transportation Canisters (1,900+ in the U.S.)

Magnastor DPC system (latest and largest to market)

- Capacity 37-PWR (equiv.)
- Thermal limits: 35.5 kW storage/ 24 kW transport
- Cooling time >4 yr from discharge

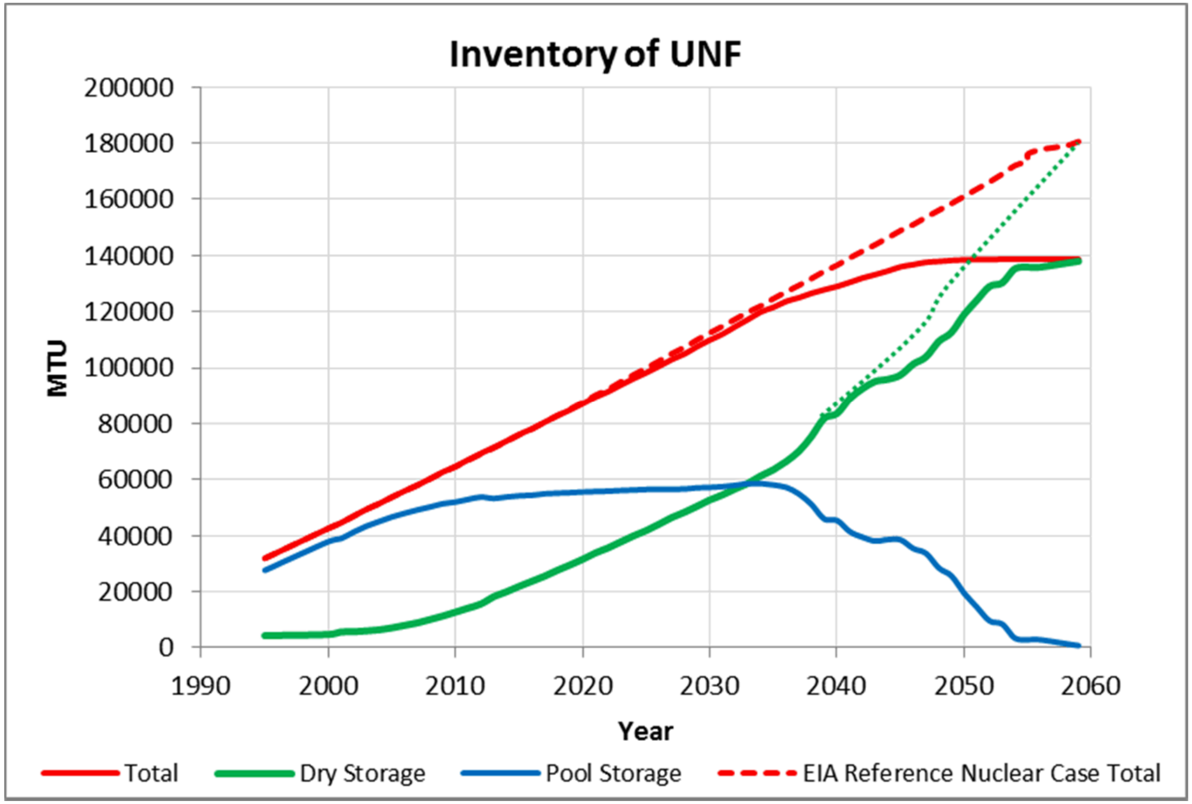
Technical issues with direct disposal:

- Repository temperature limits
- Postclosure criticality control

Pictures and data from NAC International website 31Mar2012

Projected Commercial Spent Fuel Accumulation in the U.S.

Pool Storage and Dry Storage



- **CALVIN-TSL Logistics Simulator (Nutt et al. 2012)**
- **Existing power plants with 20-year life extensions (60 years total)**
- **Burnup increase to maximum 5% enrichment**
- **Transfer from pools to dry storage at reactor shutdown**
- **Reference Case → Some new builds**

U.S. Topics to be Presented
Workshop on Design and Construction of URLs for HLW
Implementing IAEA-TC Program

- Introduction to URLs in the U.S. (A3)
  - Waste Isolation Pilot Project (WIPP)
  - Yucca Mountain Exploratory Studies Facility (ESF)
- URL planning, design, construction and operation (A4)
  - Siting, design, construction, operation and testing
  - Lessons learned
- Repository implementation (A5)
  - WIPP (design, construction, operation, radiological release)
  - Yucca Mountain (concept, design, operational safety and waste isolation)
- Geologic disposal concepts (A6)
  - General discussion (media, enclosed vs. open, package size, thermal, etc.)
  - Current status of WIPP
- Deep borehole disposal (A7)