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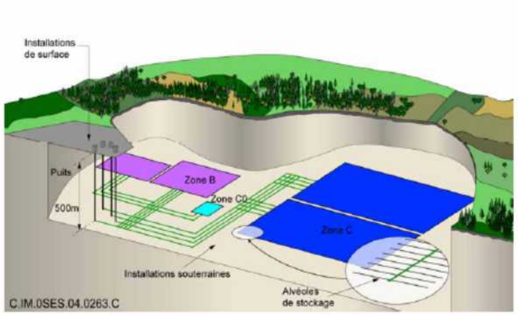

Current Status of the Back End of the US Nuclear Fuel Cycle

Evaristo J. Bonano
Senior Manager
Advanced Nuclear Energy Programs
May 17, 2015

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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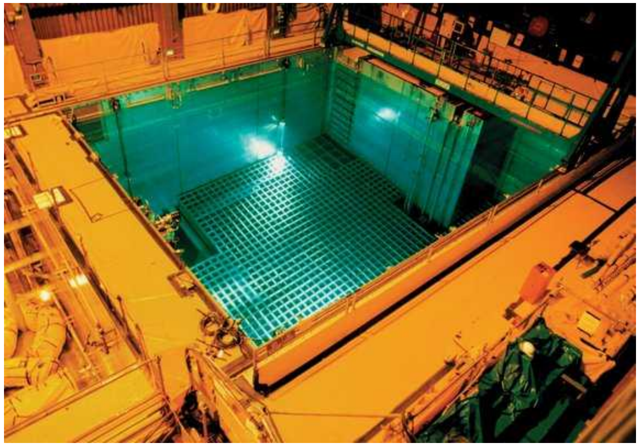
Standard Industry Practice

On-site storage of spent nuclear fuel is the only option available

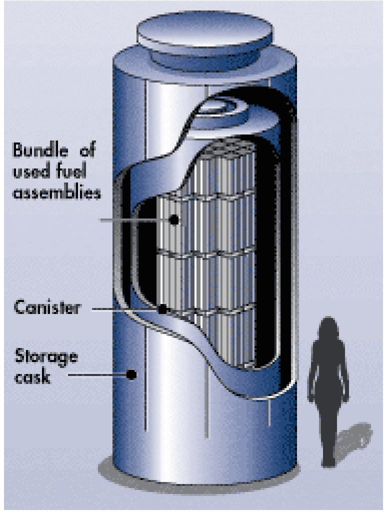


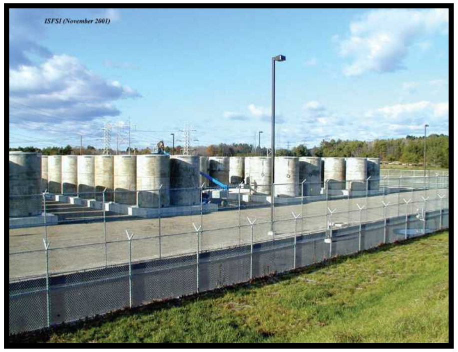
Pool Storage: essential to reactor operations, but nearing capacity, ~ 80% of existing US reactors have dry storage facilities on site

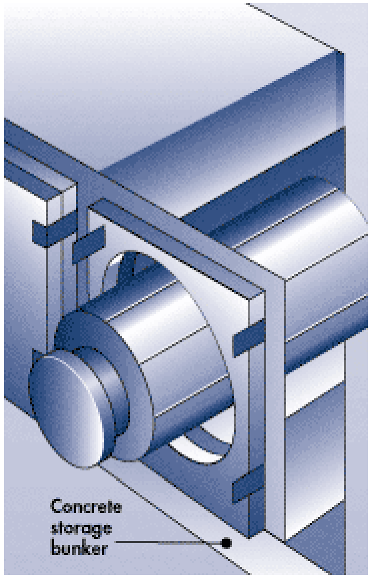
Dry Storage: horizontal and vertical concepts are in use. R&D in progress to support the technical basis for license extensions beyond original 20-yr period

Storage Terminology

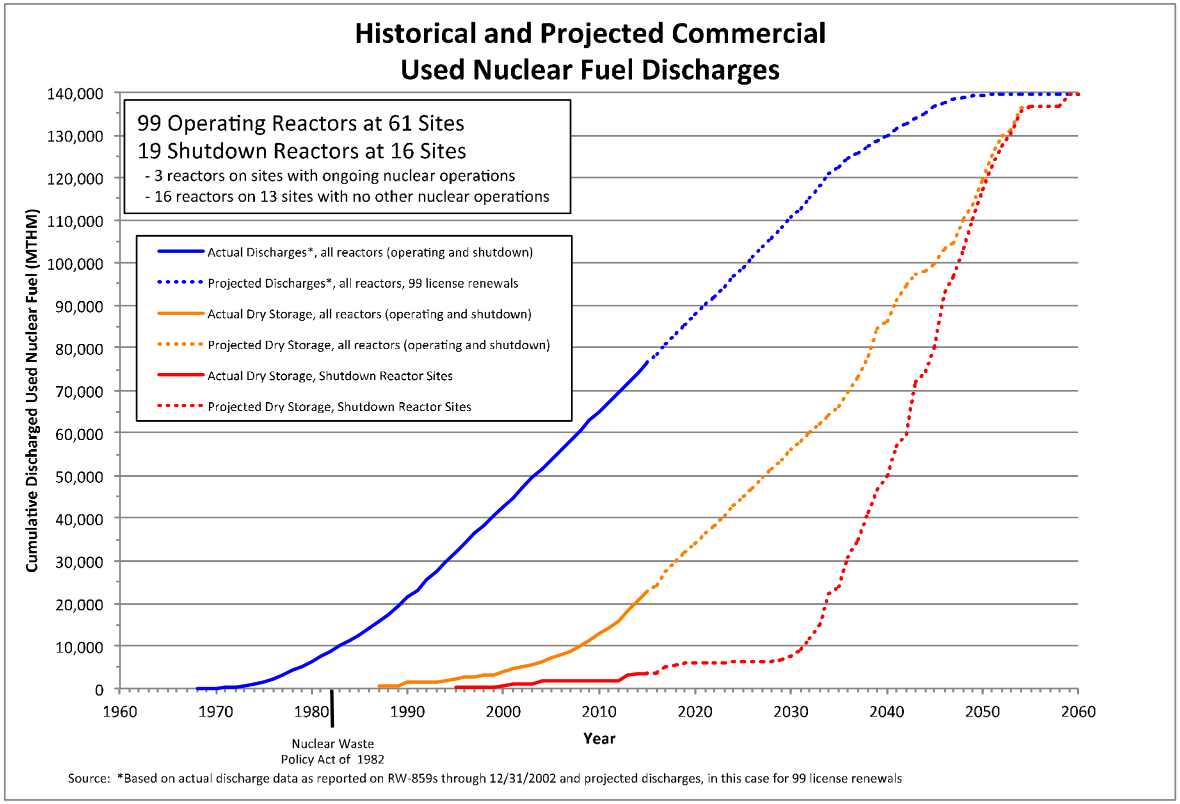
- Dual purpose canister (DPC)
  - A canister that is certified for both storage and transportation of spent nuclear fuel
- Dry cask/canister storage systems
  - The most common type of dry storage cask system is the vertical cask/canister system shown above, in which the inner stainless steel canister is removed from the storage overpack before being placed in a shielded transportation cask for transport
    - Can be constructed both above and below grade
  - Horizontal bunker-type systems and vaults are also in use
  - Some older fuel is also stored as “bare fuel” in casks with bolted lids; few sites continue to load these systems
- Multiple vendors provide NRC-certified dry storage systems to utilities



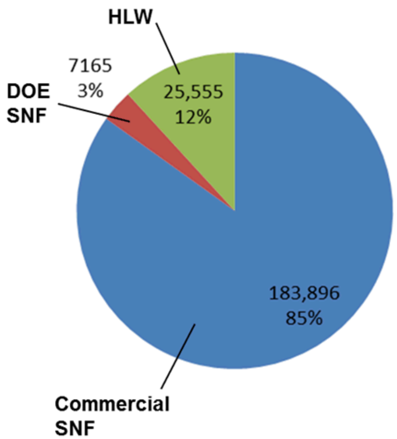




Future Projections



Projected Volumes of SNF and HLW in 2048



Volumes shown in m³, assuming constant rate of nuclear power generation and packaging of future commercial SNF in existing designs of dual-purpose canisters

Approx. 71,000 MTHM (metric tons heavy metal) of SNF in storage in the U.S. (as of 2013)

- 22,000 MTHM in dry storage at reactor sites, in approximately 1850 cask/canister systems
- Balance in pools, mainly at reactors

Approx. 2000 MTHM of SNF generated nationwide each year

- Approximately 200 new DPCs are loaded each year because reactor pools are essentially at capacity

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

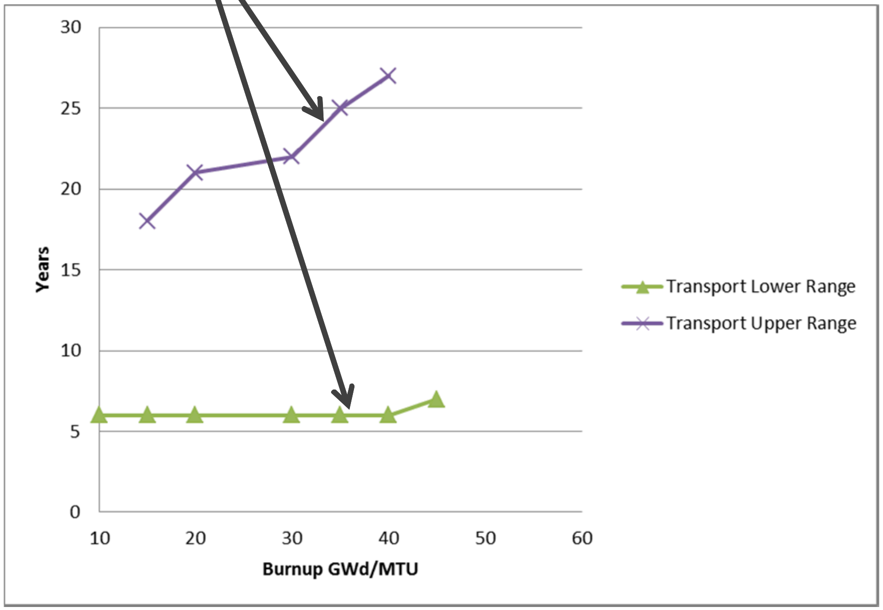
1) Repackaging spent fuel in the future
2) Constructing one or more repositories that can accommodate DPCs
3) Storing spent fuel at surface facilities indefinitely, repackaging as needed

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

Transportation Considerations

- Some DPCs may require decades of aging to cool spent fuel before they can be transported
  - High-burnup fuels may require longer aging
  - Cooling times are design-specific (in general, larger DPCs require longer cooling times)
- Transportation casks remain to be certified for some DPC systems

Range of aging times required before transport, shown as a function of burnup



Source: Adapted from Stockman and Kalinina, SAND2013-2013P

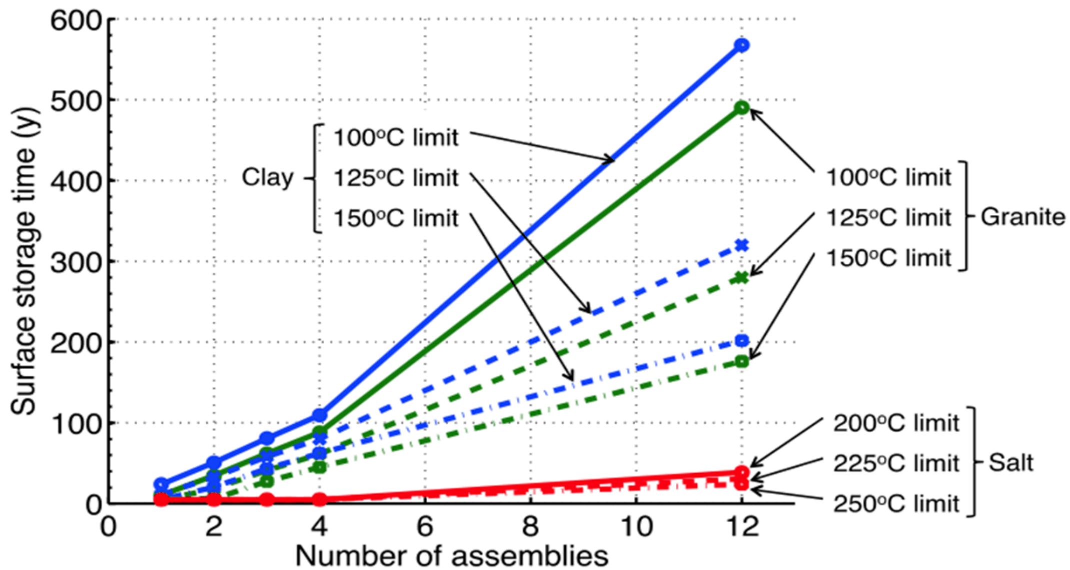
Minimum cooling times for multiple cask/canister systems, based on NRC certificates of compliance for specific designs as of 2013. Variation in times is due to the diversity of the current inventory, dominated by DPC size and heat transfer capabilities.

Repository Considerations: Thermal Management

Temperature limits based on current international and previous U.S. concepts:

- 100°C for clay buffers and clay/shale media (e.g., SKB 2006)
- 200°C for salt (e.g., Salt Repository Project, Fluor 1986)

Final temperature constraints will be site- and design-specific



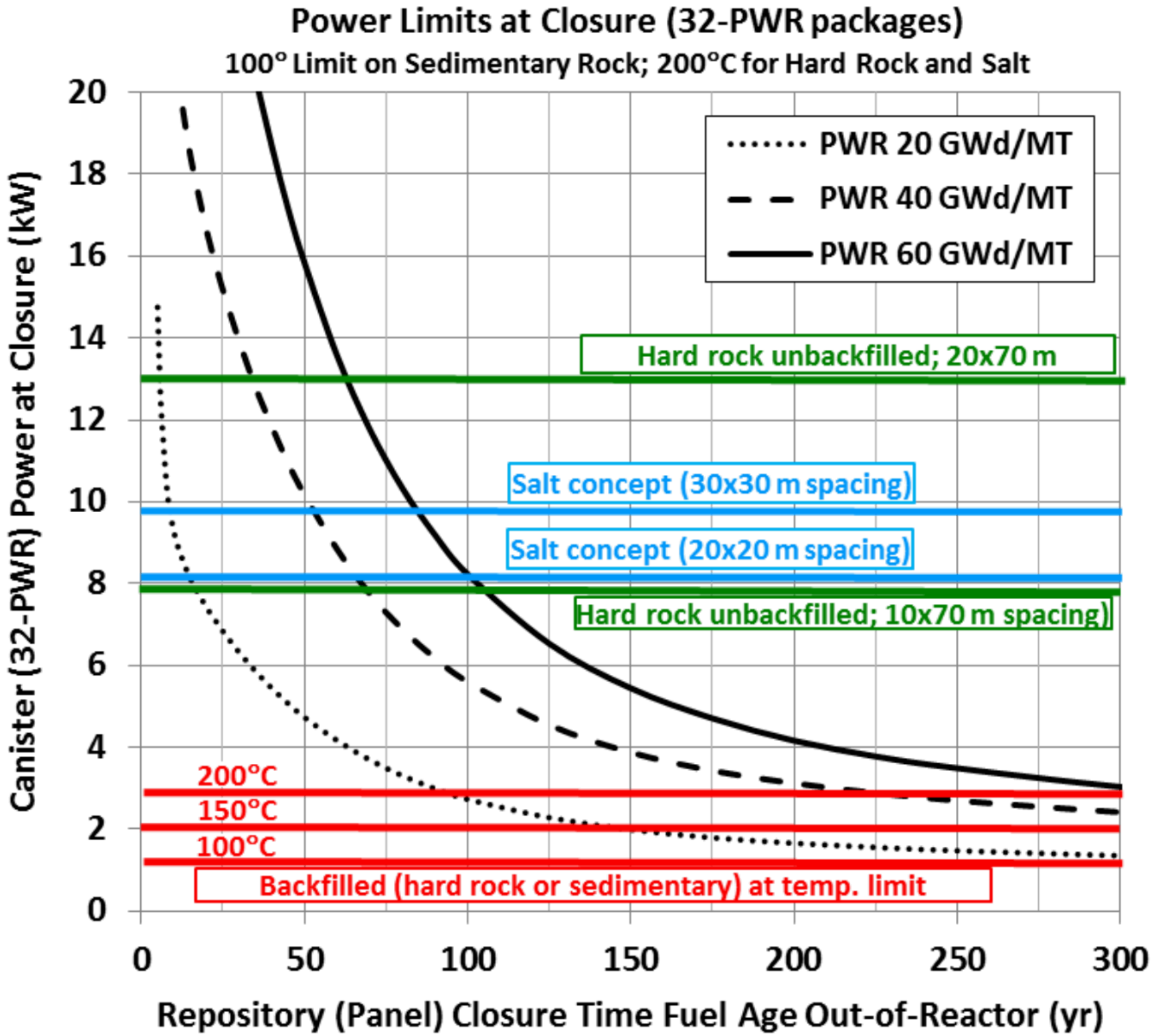
Thermal conductivity for all media selected at 100°C.

Source: Hardin et al. FCRD-USED-2012-000219 Rev. 2. 2012

Repository thermal constraints can be met by

1) Aging
2) Ventilation in the repository
3) Decreasing package thermal output (size and burn-up)
4) Increasing package and drift spacing in the repository

Thermal Load Management (cont.)



Source: Hardin et al. 2015, FCRD-UFD-2015-000129 Rev 0 Figure 2-29

Higher burnup fuels require longer preclosure cooling times

Repository designs without backfill or in high-thermal-conductivity salt will need relatively shorter preclosure cooling times to accommodate large packages; underground spacing can have a large impact

Repository designs with thermal constraints on backfill will need long preclosure cooling times to accommodate large packages

Repository Considerations:
Criticality Control

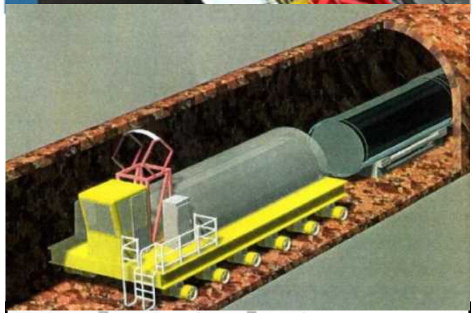
- Some already-loaded DPCs pose complications for licensing analyses of postclosure criticality control
  - Flooding by groundwater following canister degradation is a pre-requisite for criticality in any waste package
  - Al-based neutron absorbers used in some DPCs will degrade in water
  - Resulting reactivity increase can be offset by
    - High-reliability disposal overpacks
    - Uncredited margin in SNF configurations
    - High chloride content in groundwater (e.g., in salt)
  - Other options include
    - Open DPCs before disposal to add criticality controls
    - Include consequences of postclosure criticality in long-term performance estimates
  - Case-by-case analysis of individual DPCs may be needed for licensing (function of enrichment and burn-up)

Other Considerations:
Waste Package Size

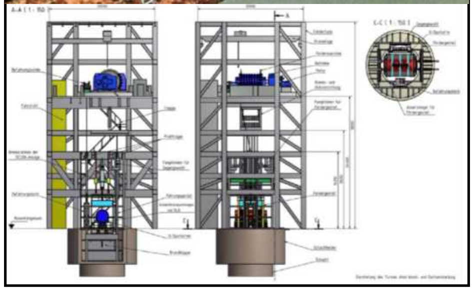
- DPCs are massive, but not unprecedented
  - Transportation, aging, and disposal canisters proposed for Yucca Mountain were in the range of sizes of existing DPCs
  - With disposal overpack and transport shielding, total mass could be on the order of 150 metric tons
- Size poses engineering challenges for handling during both transportation and disposal, but options are available

SKB Demo (90 MT), Äspö

Andra Funicular Concept



Wheelift® Transport-Emplacement Vehicle Concept



DBE Shaft Hoist Concept (85 MT)

Possible Options for an Integrated System

- Introduce a standardized canister to be loaded at reactors in the future
  - Selection of a standardized transportation, aging, and disposal (STAD) canister is repository-design and regulation specific
  - Loading STADs directly from reactor pools (as proposed for Yucca Mountain) is unlikely to happen before perhaps 2030, by which time more than 50,000 MTHM of SNF will be in DPCs
    - Later dates for repository and STAD selection will mean more fuel in DPCs
  - Lack of present incentive for utilities to use standardized canister
- Repackaging of SNF from DPCs to STADs at a consolidated storage facility
  - Cost and schedule of repackaging
  - Management of additional LLW stream (used DPCs)
- Repository design options to handle multiple packaging systems
  - Plan now for disposal of some DPCs, repackaging of others
- Cost considerations–number of handling operations, number of packages, repository design, and complexity of licensing

Note: the DOE has relevant work in progress in each of these areas

Recent DOE Work on Standardized Canisters

Sandia National Laboratories

Performance Specification for Standardized Transportation, Aging, and Disposal Canister Systems

Fuel Cycle Research & Development

Prepared for
US Department of Energy
Nuclear Fuels Storage and Transportation Planning Project

Prepared by Oak Ridge National Laboratory

July 20, 2015

FCRD- NFST-2014-000579, Rev. 2
ORNL/SPR-2015/251

https://curie.ornl.gov/content/performance-specification-and-rationale-standardized-transportation-aging-and-disposal?search_api_views_fulltext=specification

DOE Advisory and Assistance Services Contract
Task Order 21: Operational Requirements for Standardized Dry Fuel Canister Systems

UPDATED FINAL REPORT

June 19, 2015
Prepared by

https://curie.ornl.gov/content/task-order-21-operational-requirements-standardized-dry-fuel-canister-systems-updated-fina-0?search_api_views_fulltext=energysolutions

DOE Advisory and Assistance Services Contract
Task Order 18: Generic Design for Small Standardized Transportation, Aging and Disposal Canister Systems

UPDATED FINAL REPORT

May 14, 2015
Prepared by

https://curie.ornl.gov/content/task-order-18-updated-final-report-generic-design-small-standardized-transportation-aging-1?search_api_views_fulltext=energysolutions

DOE Advisory and Assistance Contract
Task Order 12: Standardized Transportation, Aging and Disposal Canister Feasibility Study

June 5, 2013
Prepared by

https://curie.ornl.gov/content/task-order-21-operational-requirements-standardized-dry-fuel-canister-systems-updated-fina-0?search_api_views_fulltext=energysolutions

Initial Standardized Canister System Evaluation

Fuel Cycle Research & Development

Prepared for US Department of Energy
Nuclear Fuels Storage and Transportation Planning Project
Josh Jarrell, Robby Joseph, Rob Howard, Richard Hale, Gordon Petersen, Blake Wilkerson
Oak Ridge National Laboratory
Jeff Fortner,
Argonne National Laboratory
Elena Kalinina,
Sandia National Laboratories

September 2015
FCRD-NFST-2014-000084 Rev. 1
ORNL/LTR-2014/330

https://curie.ornl.gov/content/initial-standardized-canister-system-evaluation-2?search_api_views_fulltext=standardization

Task Order 12: Standardized Transportation, Aging, and Disposal Canister Feasibility Study
Contract No.: A&AS DE-NE-0000291

Task Order 12 – Standardized Transportation, Aging, and Disposal Canister Feasibility Study

RPT-3008097-000

Prepared by: AREVA Federal Services LLC

REVISION LOG

Rev.	Date	Affected Pages	Revision Description
1	6-21-13	2, 5, E-28	Changes DOE nomenclature on page 2 Replaced Figure 2 in Executive Summary; Deleted Section E.2.1.2..

Task Order 12: Standardized Transportation, Aging, and Disposal Canister Feasibility Study
June 14, 2013

https://curie.ornl.gov/content/areva-task-order-12-standardized-transportation-aging-and-disposal-canister-feasibility?search_api_views_fulltext=standard&f[0]=field_document_type%3A1&order=field_publication_date&sort=desc

Internet search on "standardized transportation aging and disposal canister"

International Perspectives

- *Potential Interface Issues in Spent Fuel* Management, IAEA- TECDOC 1774, 2015:
  - "A systems approach is needed to ensure that influences from and impacts on all phases of [the back end of nuclear] fuel cycle are taken into account when making decisions."
  - "The biggest uncertainty in successfully integrating the [back end of the nuclear fuel cycle] is the uncertainty relative to the end point." In the US, the "end point" is geologic disposal.
  - Successful integration requires an understanding of the full cycle and the **willingness to make trade-offs** [emphasis added] that assure success over all phases of the [back end of the nuclear fuel cycle] rather than optimizing for particular interfaces …"
  - "Effective integration begins early in the planning process. Opportunities are lost if interfaces are not identified and addressed in the early stages of each of the [back end of the nuclear fuel cycle] phases."

Legislative, Regulatory, and Stakeholder Topics

- All paths will require legislative and regulatory actions
- All paths will require consideration of multiple stakeholder positions
  - Existing site communities
  - Transportation corridor communities
  - Future storage site communities
  - Future disposal site communities
  - Geographically dispersed communities and organizations
  - Site operators
  - Ratepayers
  - Taxpayers

Discussion

- Questions for the group to consider over the next two days:
  - What would a better fuel management system look like?
  - What metrics should we use to judge a spent fuel management system? (e.g., cost, safety, security?)
  - What barriers prevent the US from implementing a better system?
  - Are the benefits of a better system worth the cost?
  - What can the nation do now that will impact future practice?
  - Can we plan for flexibility and contingency in case a stable national policy is not achieved?
  - What are the implications of doing nothing now?

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