Integrating Fuel Cycles, Spent Fuel Storage, and Repositories

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Policies / Technologies Change Faster than Fuel Cycles and Repository Programs

- 1960s
  - Uranium is scarce thus reprocess SNF and recycle fissile materials
  - SNF storage at reprocessing plant to provide operating inventory
- 1980s
  - Nonproliferation concerns and abundant uranium: no reprocessing
  - Policy of direct disposal of SNF
    - Did not build repository-required 40 to 60 years of SNF storage before disposal
    - Sweden built SNF storage in the 1980s to support their repository
- Do not know today if SNF is a waste or resource
  - Need robust strategy for uncertain futures
  - Must consider all fuel cycle steps
  - Starting point: Define desired endpoints and then connect to where we are today
  - Four possible backend fuel cycle futures (Endpoints)

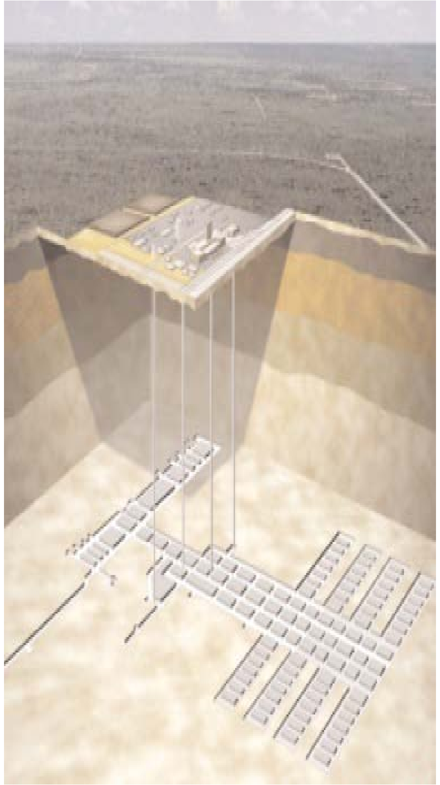
SNF Storage: A Requirement

- Repository
  - Store SNF/HLW for 40 to 60 years before disposal: Options:
    - At reactor
    - Centralized storage facility
    - Repository with active ventilation for 40 to 60 years
  - Storage universally adopted to reduce decay heat to:
    - Reduce costs
    - Reduce repository uncertainties associated with decay heat
  - Sweden built centralized storage facilities in the 1980s to support their repository program
- Closed fuel cycles: Reprocessing
  - Large centralized storage with reprocessing plants
  - Provides inventory to select SNF to obtain desired plutonium isotopics for MOX fuel fabrication
  - France, Great Britain, and Japan have centralized storage with reprocessing facilities

Option 1:
Traditional Repository

Current U.S. Policy

Repository Disposes of Waste

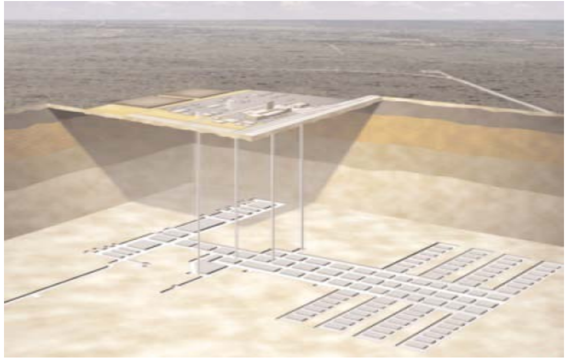


- Repository choices are separate from fuel cycle choices
- Separate institutions for fuel cycles, SNF storage, and waste management
- Assumes known path to the future

Option 2: Open Fuel Cycle: Repository with SNF Retrievability

Disposal Today: Options for the Future

Combine SNF Storage and Repository



- Design repository with two goals:
  - Long-term waste isolation
  - SNF can be retrieved for centuries
- Some repository designs have this capability
  - France (intentional)
  - Sweden (not intentional)

Incentives for Combined Facility

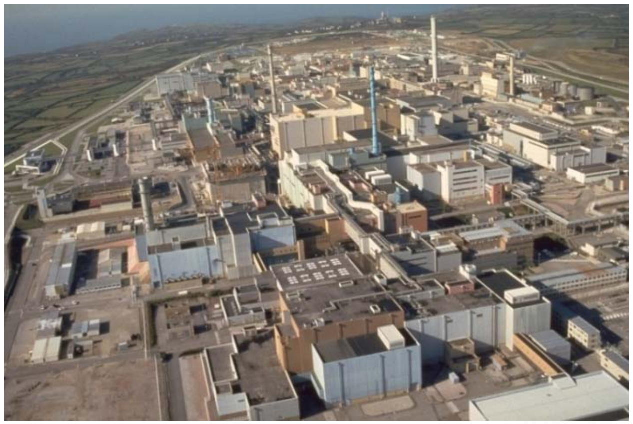
- Policy and Intergenerational Equity
  - Dispose of waste when repository becomes available
  - Maintain option for future generations to recover SNF—a long-term SNF storage option
- Public assurance of repository performance
  - Reversible system by design
  - Large segments of the public do not trust technology options—wants backup

Option 3: Collocation of Backend Fuel Cycle and Repository Facilities

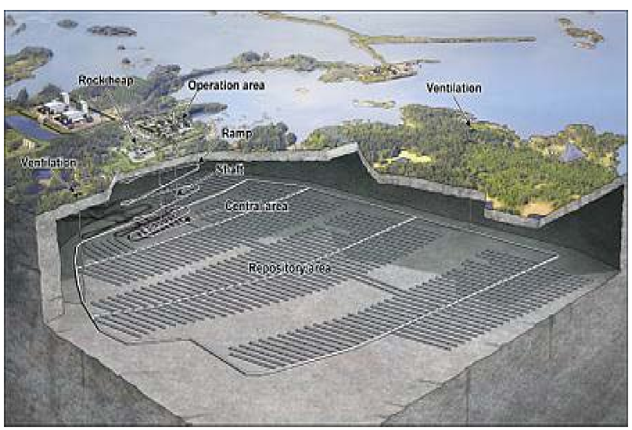
Collocate and Integrate SNF Storage, Reprocessing, Fuel Fabrication, and Repository For Closed Fuel Cycles

C. W. Forsberg and L. R. Dole, “Collocation and Integration of Reprocessing, Fabrication, and Repository Facilities to Reduce Closed Fuel Cycle Costs and Risks,” Paper 10197, International Congress on Advanced Nuclear Power Plants, ICAPP’10, San Diego, June 13-17, 2010

Combine SNF Storage, Reprocessing, Fuel Fabrication, and Repository



LaHague (France): Reprocessing



Forsmark (Sweden): Repository

- Integrated facility with two goals two goals:
  - Produce recycle fuel assemblies
  - Dispose of all wastes in the on-site repository
- Requires repository before implementing closed fuel cycle
- Changes back-end fuel-cycle technical constraints
  - No transportation
  - No waste volume constraints

Incentives for Collocation of Closed Fuel Cycle Facilities and Repository

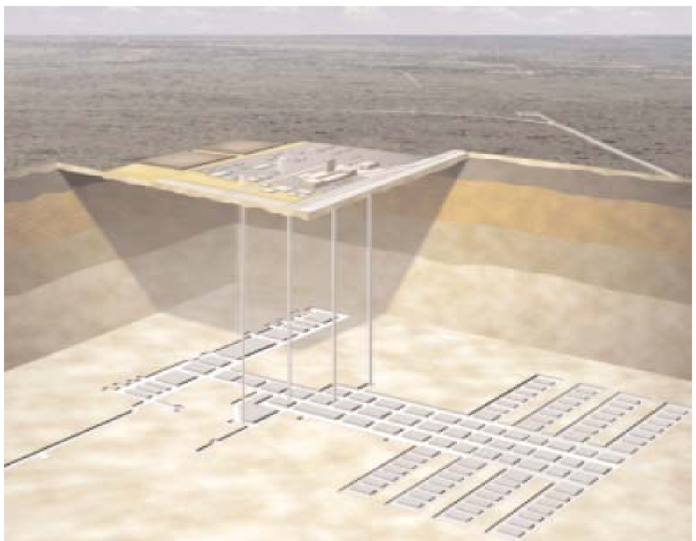
- Potential fuel cycle gains from changing technical constraints
  - Lower costs and risks
  - Improved repository performance (Wider waste form choices with relaxed volume constraints)
  - Termination of repository safeguards (Low waste loadings until plutonium "not practically recoverable")
- Community with repository receives:
  - Few hundred jobs with repository
  - Thousands of jobs with SNF storage, reprocessing, and fuel fabrication
  - Industrial facilities on tax roles

Option 4:
Multi-Repository Systems

Different Facilities: Different Characteristics

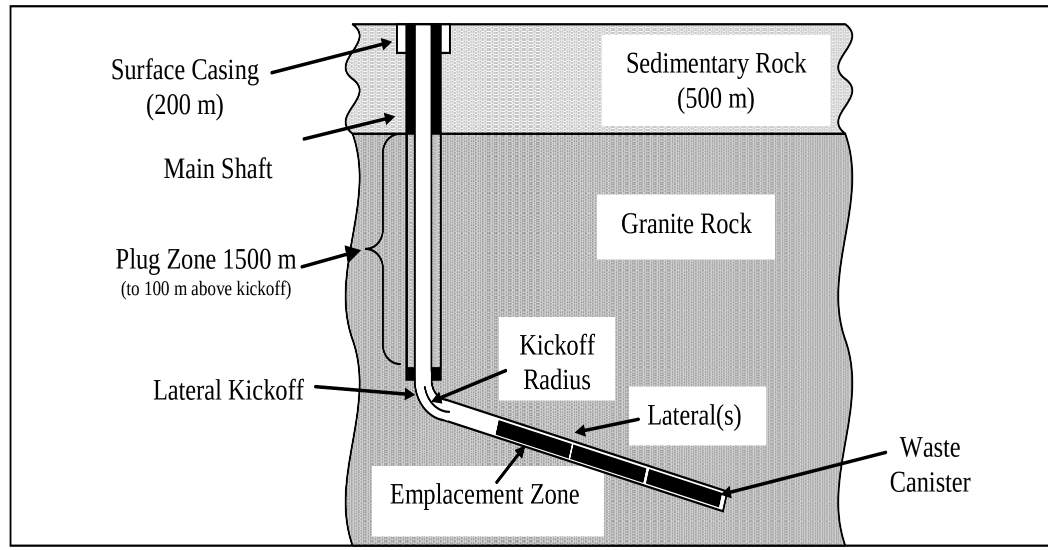
Multi-Repository Systems: Different Facilities With Different Capabilities

High Volume



- Conventional repository
- High-volume wastes

High Performance



- Borehole, Salt diver, etc.
- Low-volume waste missions
  - Regional repositories
  - Disposal of long-lived or high-heat radionuclides

Incentives for Advanced Options Such as Borehole Dispsoal

- Open fuel cycle: Regional disposal of SNF
  - Technology may enable economic small repositories
  - Unexplored set of options
- Closed fuel cycle:
  - Disposal of troublesome radionuclides
    - High-heat radionuclides
    - Minor actinides
- Not yet an assured option that one can bet on

Conclusions

- Must integrate fuel cycles, SNF storage, and repository systems
- Need robust solutions that are viable with changing policies and technologies
- Think about endpoints: Two recommendations:
  - Repository with retrievable SNF
  - Create option for collocated and integrated back-end facility for cost, safety, nonproliferation, and public acceptance
- R&D needed to determine full set of options—such as borehole and regional repositories

Added Information

Biography: Charles Forsberg

Dr. Charles Forsberg is the Executive Director of the Massachusetts Institute of Technology Nuclear Fuel Cycle Study. Before joining MIT, he was a Corporate Fellow at Oak Ridge National Laboratory. He is a Fellow of the American Nuclear Society, a Fellow of the American Association for the Advancement of Science, and recipient of the 2005 Robert E. Wilson Award from the American Institute of Chemical Engineers for outstanding chemical engineering contributions to nuclear energy, including his work in waste management, hydrogen production and nuclear-renewable energy futures. He received the American Nuclear Society special award for innovative nuclear reactor design. Dr. Forsberg earned his bachelor's degree in chemical engineering from the University of Minnesota and his doctorate in Nuclear Engineering from MIT. He has been awarded 11 patents and has published over 200 papers including multiple papers on design options for repositories and alternative geochemical methods to reduce radionuclide releases from repositories.

Summary

- We do not know today if LWR SNF is a waste or resource
- We need strategies that maintain options for different futures—options with defined end points
- There are four ways to couple SNF storage, fuel cycles, and repositories—need to consider options
  - Repository disposes of waste: Existing U.S. policy
  - Repository with long-term retrievability of SNF
  - Collocation and integration of closed fuel cycle facilities (SNF storage, reprocessing plant, fabrication plant, repository) at repository site
  - Multi-geological waste isolation systems
- Endpoint recommendations
  - Multi-century retrievability of SNF
  - Collocation and integration of all back-end facilities: SNF Storage, Reprocessing, Fuel fabrication, and Repository

Collocation and Integration of Reprocessing, Fabrication, Repository Facilities to Reduce Closed Fuel Cycle Costs and Risks

Original Presentation Given at ANS/ICAPP Conference: June 2010

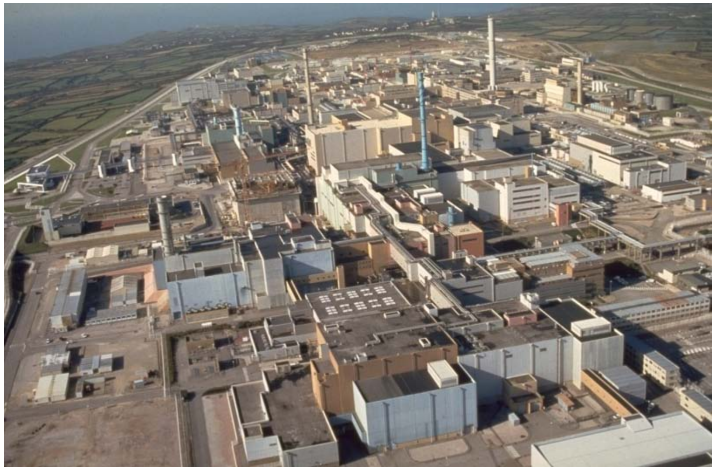
C. W. Forsberg and L. R. Dole, “Collocation and Integration of Reprocessing, Fabrication, and Repository Facilities to Reduce Closed Fuel Cycle Costs and Risks,” Paper 10197, International Congress on Advanced Nuclear Power Plants, ICAPP’10, San Diego, June 13-17, 2010

Co-Locating Reprocessing and Waste Disposal Facilities Has Major Impacts

Hanford (Washington State)

- On-site waste disposal
- 5000-7000 MTU/y (33 MTU/day maximum)
- Low-burnup defense SNF
- Large facility

LaHague (France)



Courtesy of COGEMA

- Off-site waste disposal
- 2 x 800 MTU/y
- Commercial SNF
- **Much larger facility**

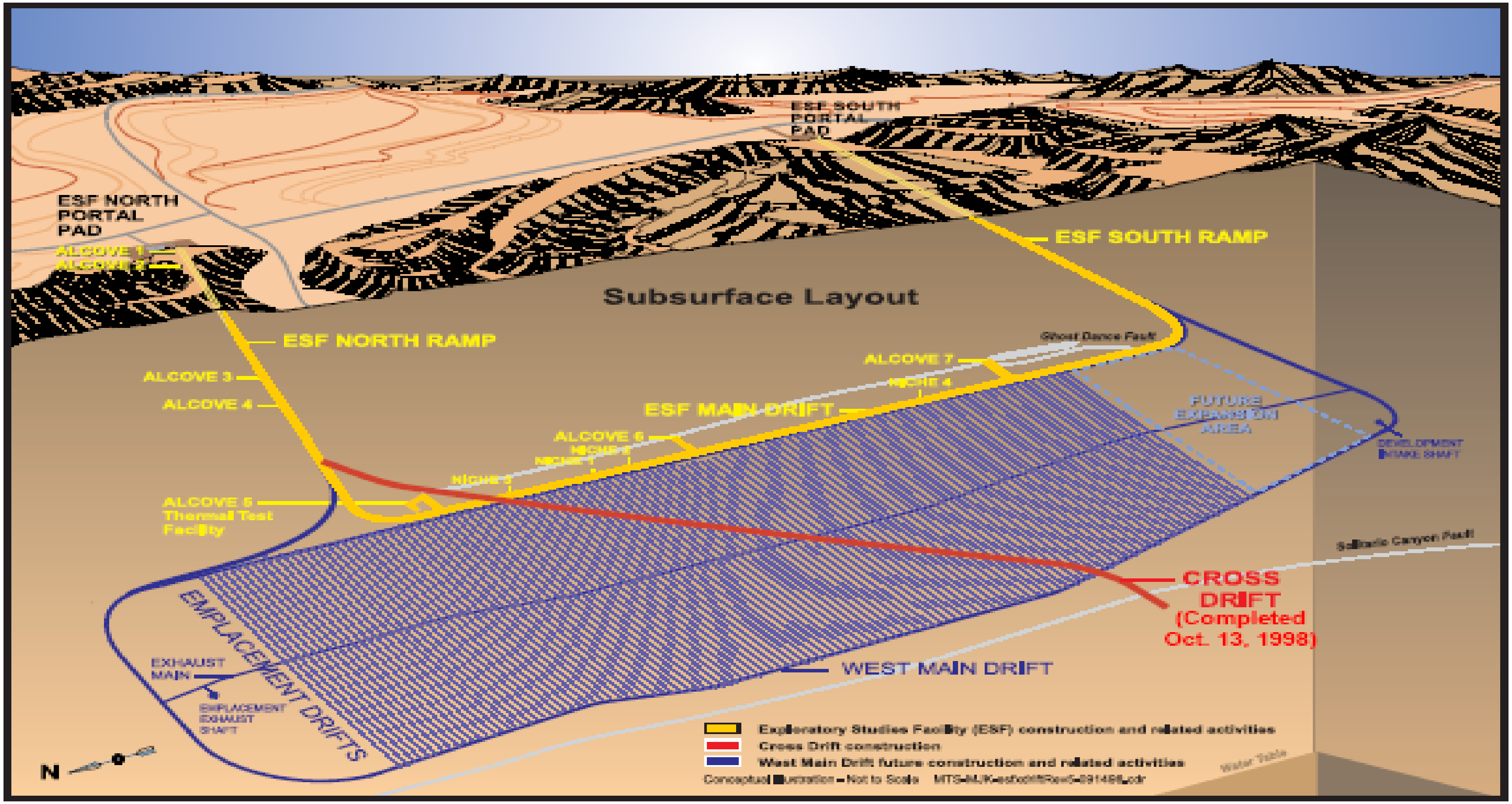
M. S. Gerber, A Brief History of the Purex and UO3 Facilities, WHC-MR-0437 (1993)

Hanford Purex Reprocessing Was Inexpensive But It Made a Mess

- **How would cost and risk change if co-locate and integrate reprocessing, fuel fabrication, and repository facilities?**
  - With a strict waste management strategy
  - With very high safety standards
  - With improved safeguards
- **Co-siting changes the ground rules**
  - Reduced waste volume constraints
  - Different institutional structures

Repository Disposal of High-Heat Waste is Expensive

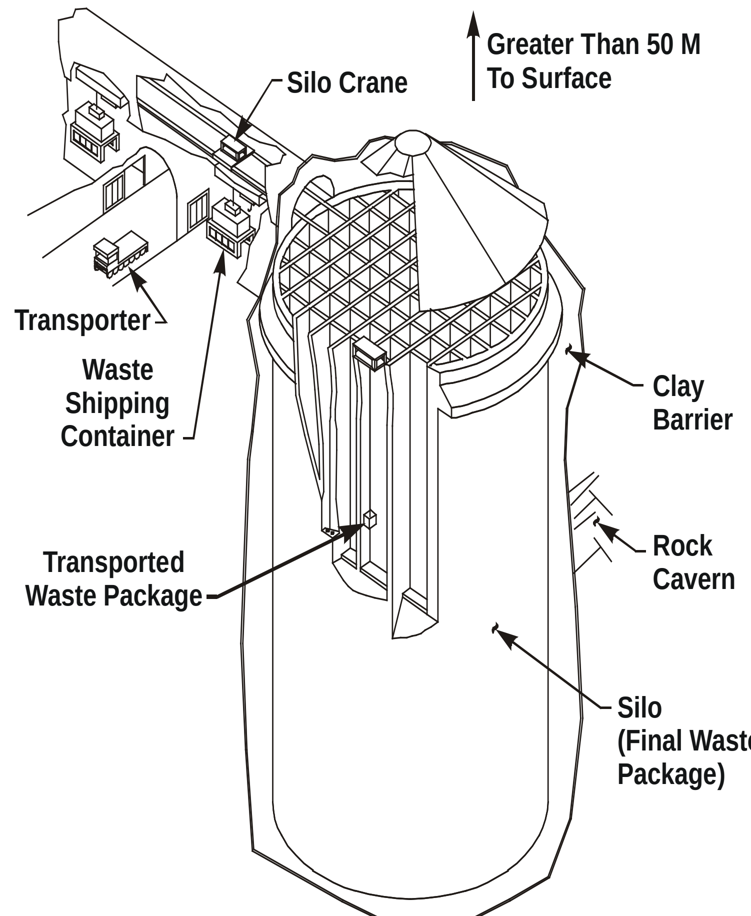
Must Spread Wastes Out Over a Large Area



Long-Lived Low-Heat Wastes Have Low Repository Disposal Costs

Waste Isolation Pilot Plant

Swedish SFR Silo



Large Waste Volumes: Not a Challenge for On-Site Disposal

Collocation Enables Use of Lower-Cost Processes

Example: Chemical Decladding SNF

- Traditional commercial process
  - Mechanical removal of cladding
  - Complex and expensive
- Chemical decladding
  - Traditional defense plant strategy
  - High volume (Hanford) throughput
  - Lower-cost, smaller facilities
  - Larger waste volumes
    - Potentially inexpensive if on-site disposal
    - Expensive if ship off site

Higher-Volume Waste Forms Can Improve Repository Performance

Integrated Collocated Reprocessing, Fabrication, and Repository Facility

- Isotopically dilute solubility-limited radionuclides (^{131}I, ^{14}C, etc.) with non-radioactive elements and solidify mixture
  - If isotopically dilute by a factor of 100, reduce waste release rate by a factor of 100
  - Simple strategy to improve performance
- Reduce waste-form radiation damage with low radionuclide concentrations in waste

Reduced Volume Constraints Enables Termination of Repository Safeguards

Integrated Collocated Reprocessing, Fabrication, and Repository Facility

- Safeguards required for wastes with significant fissile materials
- Can terminate long-term repository safeguards by dilution until “not practically recoverable”
- Simple solution but requires repository to accept larger waste volumes

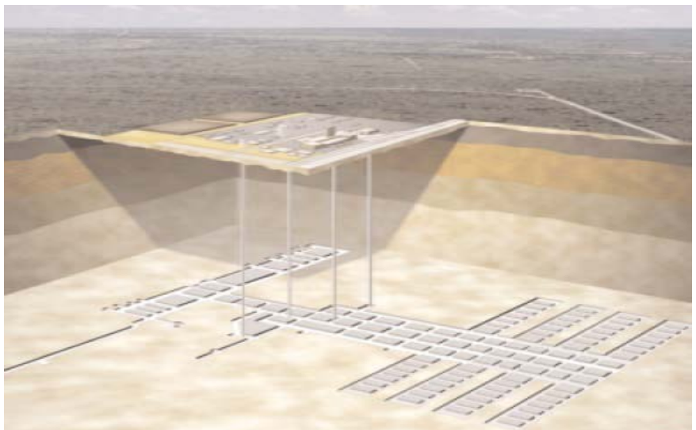
Collocation and Integration Can Reduce Operational Risks

Integrated and Collocated Reprocessing, Fabrication, and Repository Facility

- Reduce probability of accidents by simplified processes
- Reduce consequences of accidents by minimizing unprocessed waste inventories
  - Same day disposal
- Geological disposal of all wastes

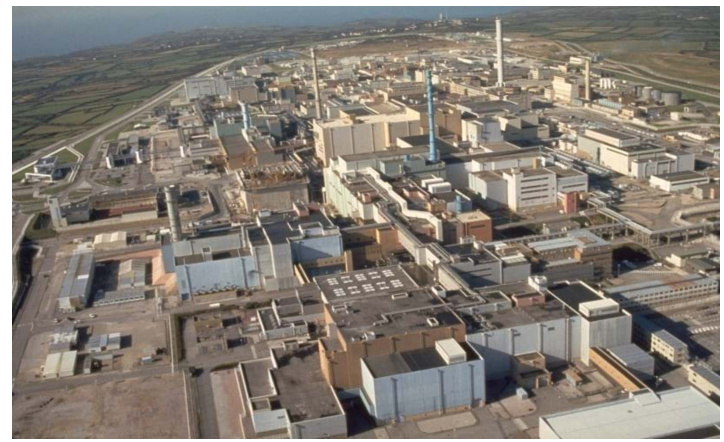
Combining Facilities May Change System Acceptability

WIPP (New Mexico)



- Repository
- Few hundred jobs
- No tax revenue

LaHague (France)



Courtesy of COGEMA

- Reprocessing
- 5000 high-paying jobs
- Local support

Reprocessing-Fabrication Facilities Are Larger than Repository Facilities

Institutional Implications of Combined Single Back-End Facility

- May assist repository siting by coupling repository to potentially large future back-end facilities (jobs and tax revenue)
- Greater equity—benefits and liabilities to the same community and state
  - U.S. has separated fuel cycle benefits from waste management liabilities
- Reduces other institutional challenges
  - Less transportation
  - Reduced safeguards regime

Relative Scale of U.S. Defense and Commercial Facilities

Subject	U.S. Defense	Commercial
Reprocessing plant throughput (MTU/day)	33[1]	5 (Built, not operated)[3]
Typical burnup (MWd/ton)	100s-1000s	10,000s (To ~60,000)
Waste management	On site (Original)	Off site
SNF tons (Defense processed / total civilian inventory)	>100,000[2]	~60,000

[1]M. S. Gerber, *A Brief History of the Purex and UO_3 Facilities*, WHC-MR-0437 (1993)

[2]U.S. DOE, *Historical Generation and Flow of Recycle Uranium in the DOE Complex: Project Plan*, (February 2000)

[3]Reprocessing Facilities: Barnwell AGNES, Nominal 1500 tons/y (5 tons/day nominal); British B205 Magnox ran at >1100 tons/y and Thorp (oxide fuel) nameplate was 1200 t/y; designed for 6000t oxide fuel over 10 years