Specialized Disposal Sites for Different Reprocessing Plant Wastes

Charles W. Forsberg*
and Michael J. Driscoll**

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Oak Ridge National Laboratory*
P.O. Box 2008, Oak Ridge, TN., 37831
United States of America
E-mail: forsbergcw@ornl.gov

****Massachusetts Institute of Technology**
77 Massachusetts Avenue
Cambridge, Massachusetts 02139
E-mail: mickeyd@mit.edu

OAK RIDGE NATIONAL LABORATORY

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Abstract

Specialized Disposal Sites for Different Reprocessing Plant Wastes

Charles W. Forsberg and Michael J. Driscoll

Once-through fuel cycles directly dispose of one primary waste form: spent nuclear fuel (SNF). In contrast, the reprocessed SNF yields multiple waste streams with different chemical, physical, and radionuclide characteristics. These different characteristics of each waste stream imply that there are potential cost and performance benefits to developing different disposal sites that best match the disposal requirements of each waste stream. Disposal sites as defined herein may be located in different geologies or in a single repository containing multiple sections, each with different design characteristics. The paper and associated viewgraphs describes the results of a series of studies on disposal options for specific wastes and the potential for a waste management system that better couples various reprocessing plant wastes with disposal facilities.

Context of Study

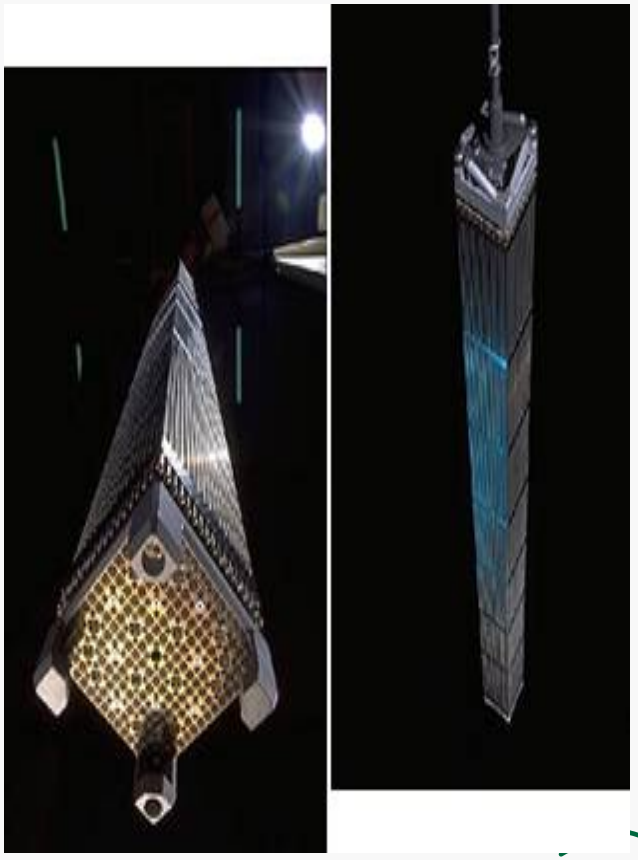
- **There have been many studies by the authors and others on how to dispose of wastes with specific characteristics**
- **Reprocessing creates multiple waste forms and the potential for custom waste disposal of different waste forms in the same repository or different repositories**
  - **Potential for major cost savings**
  - **Potential for major reductions in repository risk independent of whether any wastes are destroyed (transmuted)**
- **The paper describes options with references to major subsets of options**
- **The presentation gives a few examples**

Reprocessing Waste are Different than Spent Nuclear Fuel (SNF)

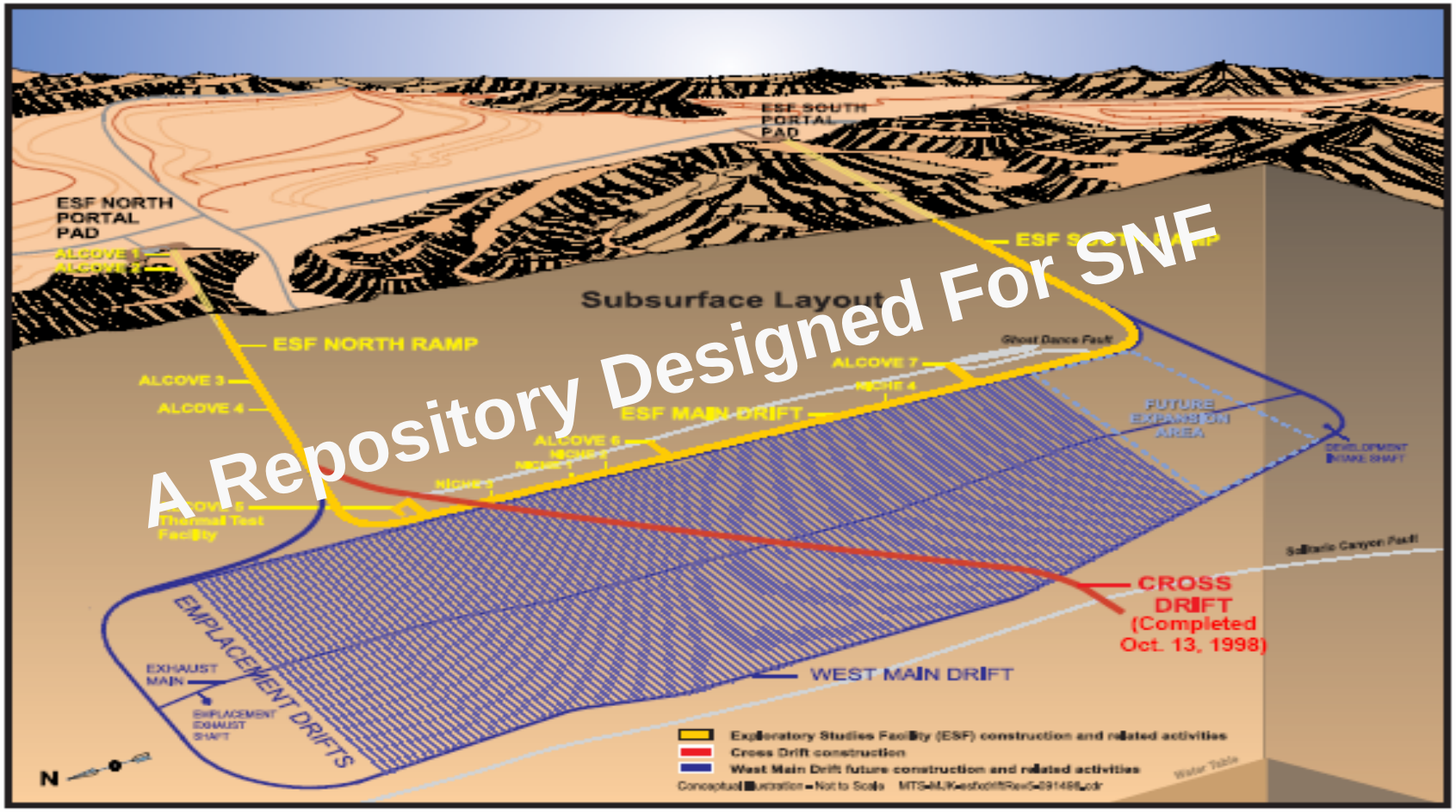
Reprocessing
Multiple Wastes

- **Plutonium/Uranium**
- **High-Heat Wastes**
  - **^{90}Sr, ^{137}Cs**
- **Minor Actinides**
  - **Np, Am, Cm**
- **Volatiles (Kr, Xe, etc.)**
- **Very Low-Heat Wastes**
  - **Remainder**
- **Cladding**

SNF
Single Waste



If SNF is Reprocessed, We can Reduce Repository Costs and Improve Performance by Rethinking Design



A Repository Designed For SNF

Disposal Options for Specific Reprocessing Wastes

High-Heat Wastes

Low-Heat Wastes

Long-Lived Radionuclides that Control Repository Performance

Repository Redox

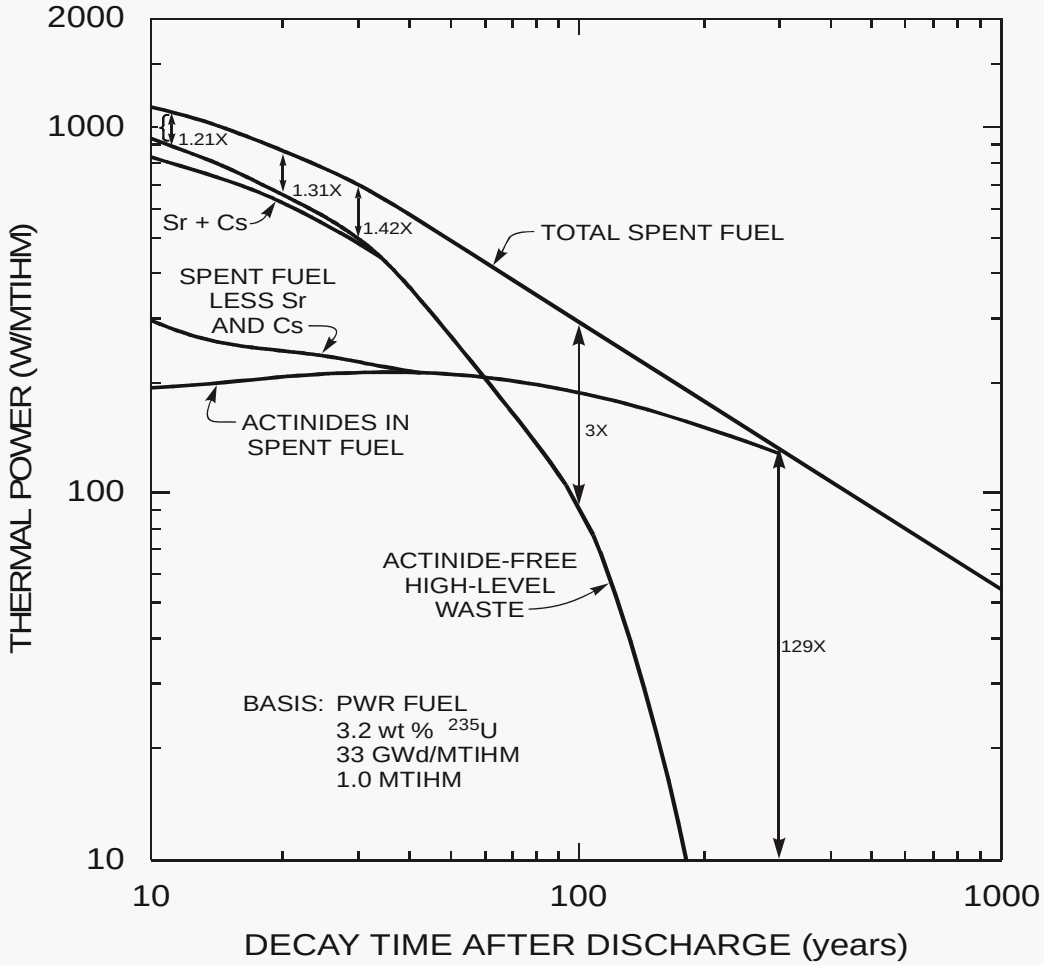
High-Heat Waste Disposal

Repository Size and Cost
is Controlled by Decay Heat

Options Exist to Reduce this Constraint

Decay Heat Versus Time

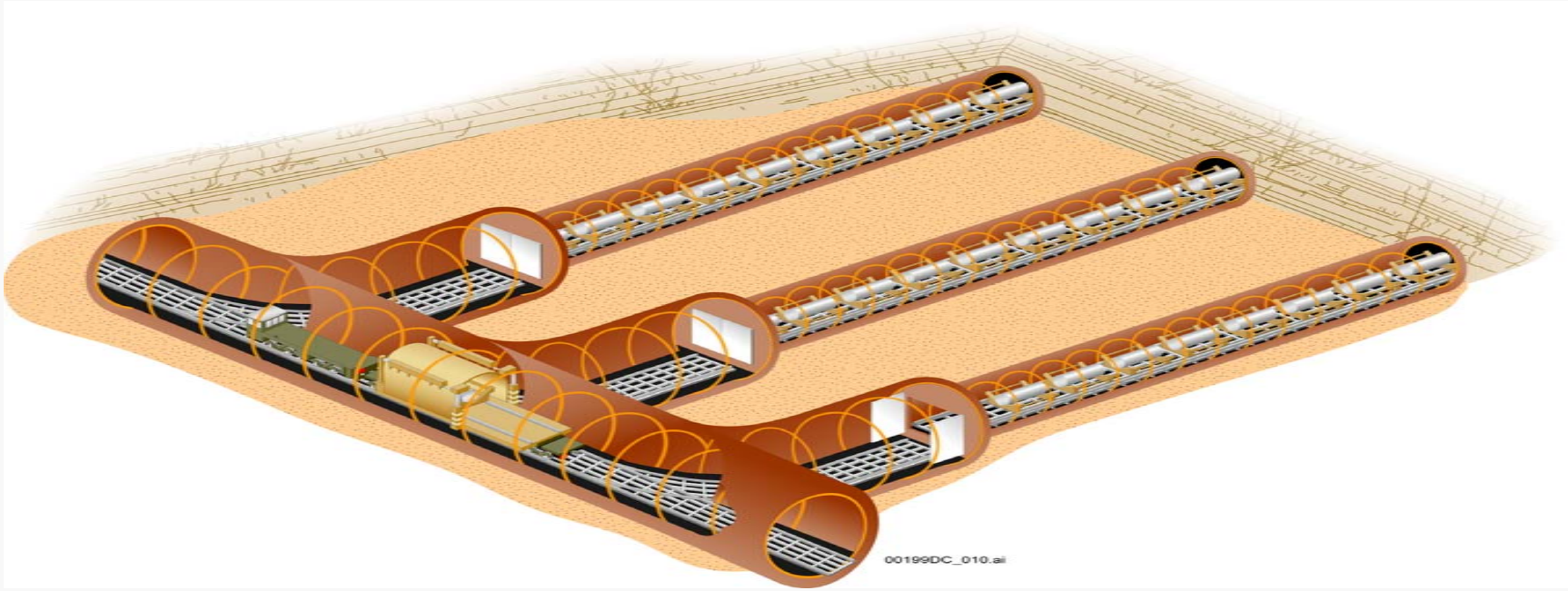
- **^{90}Sr and ^{137}Cs control decay heat for decades**
- **Longer times are controlled by actinides**
- **If reprocess and remove actinides, ^{90}Sr and ^{137}Cs dominate the decay heat and thus the repository design for centuries**



ORNL DWG 92C-242R

High-Heat Wastes Control Repository Size

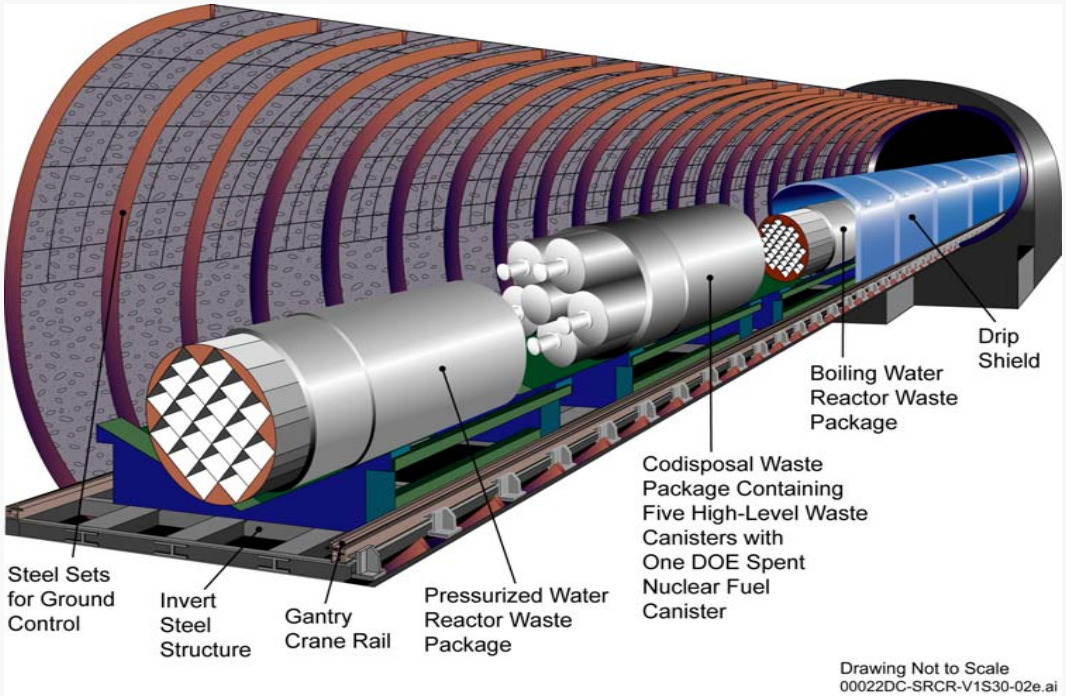
Wastes Spread Out to Remove Heat



The Repository is Designed Like a Big Automobile Radiator: Parallel Tunnels are Expensive as Underground Radiators

Option I: To Eliminate Cs/Sr Control of Repository, Ventilate for >100 Years

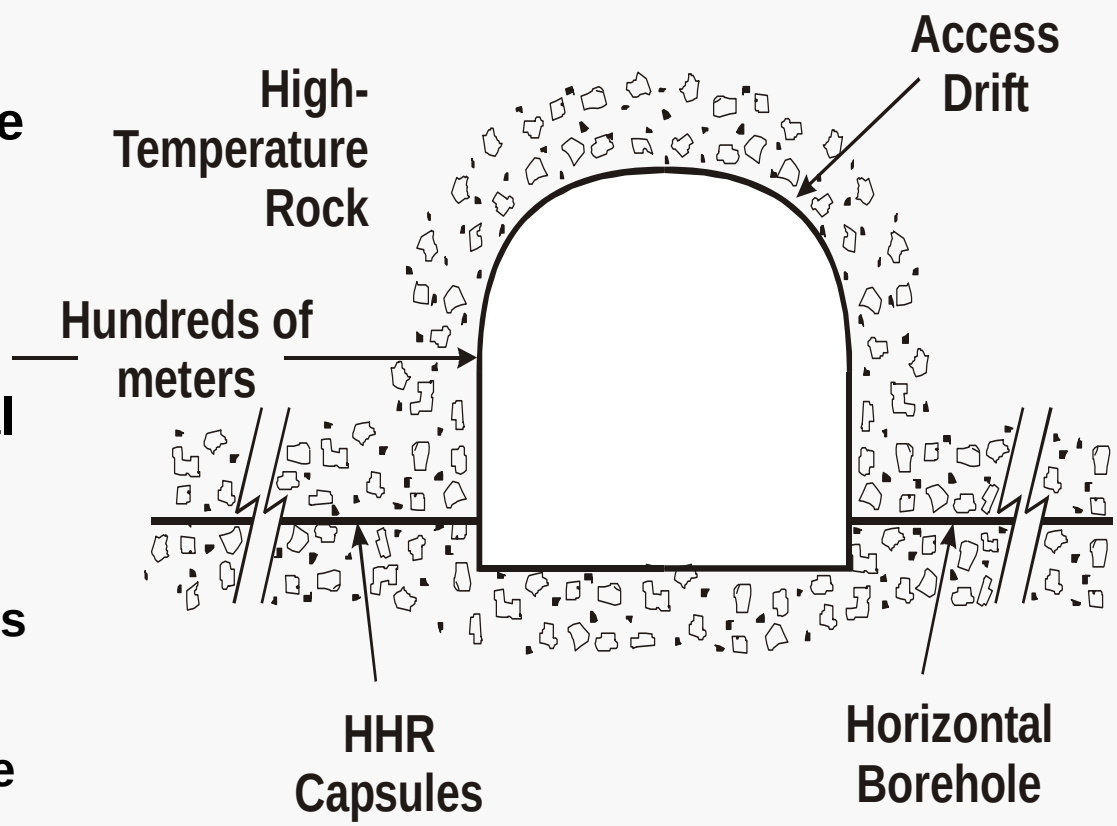
- **Repository will remain open for >50 years**
  - **Long-term monitoring**
  - **Build case for closure**
  - **Keep open fuel-cycle options**
- **Can make the choice to fully ventilate the repository**
  - **Active cooling**
  - **Reduces other uncertainties**



Option II: Dispose of $^{90}Sr/^{137}Cs$ in Small Horizontal Boreholes

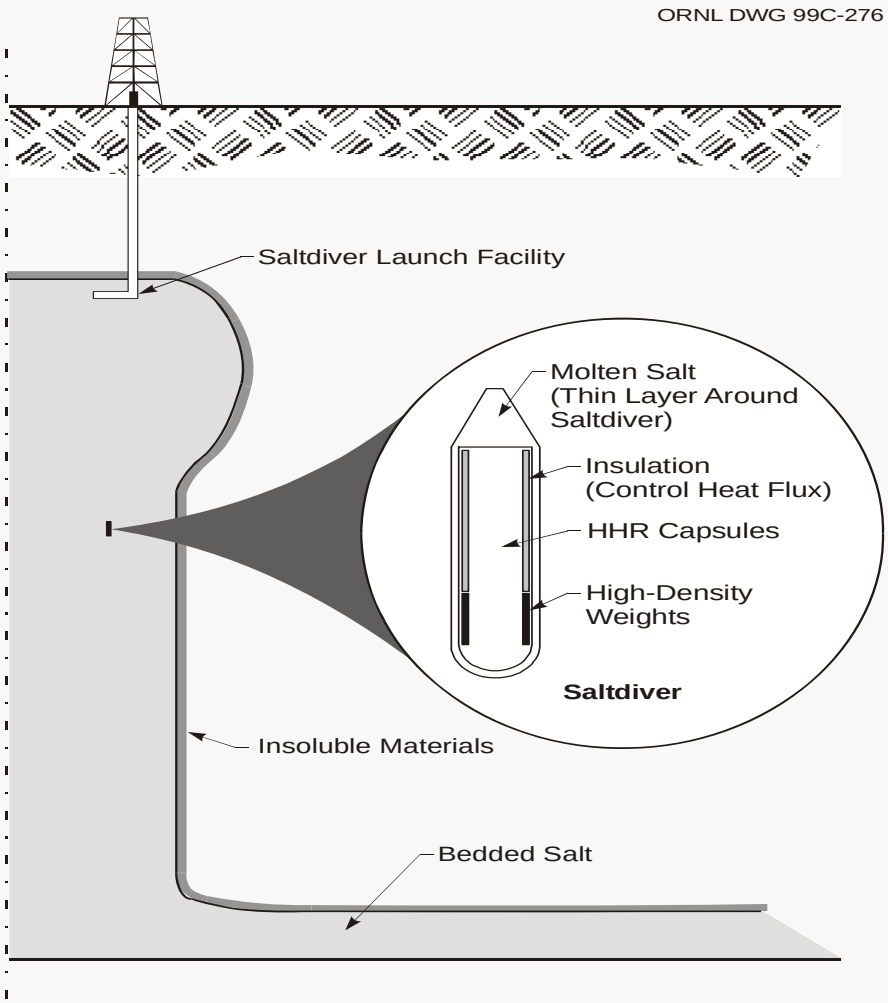
ORNL DWG 99C-391R

- **$^{90}Sr/^{137}Cs$ have small volumes**
- **Design section of the repository as a radiator with small tubes for high-heat wastes**
- **Allow very high local temperatures**
  - **Stay above the boiling point of water until $^{90}Sr/^{137}Cs$ decay**
  - **Option uses a very small fraction of the repository space**



Option III: Separate $^{90}Sr/^{137}Cs$ Disposal

- **Salt Diver**
  - **High-heat wastes in container**
  - **Wastes sink in salt**
  - **Salt becomes plastic as heated (normally a design constraint in salt repositories)**
- **Very low costs**
- **Simple performance assessment**
  - **Limited lifetime of ^{90}Sr and ^{137}Cs**
  - **Disposal to 10,000 m**
  - **Known behavior of salt**



Salt Dome With Saltdiver

Low-Heat Wastes

(What Remains if Major Heat-Generating Radionuclides are Removed)

Ideal Repository Design and Waste Package for Low-Heat Wastes

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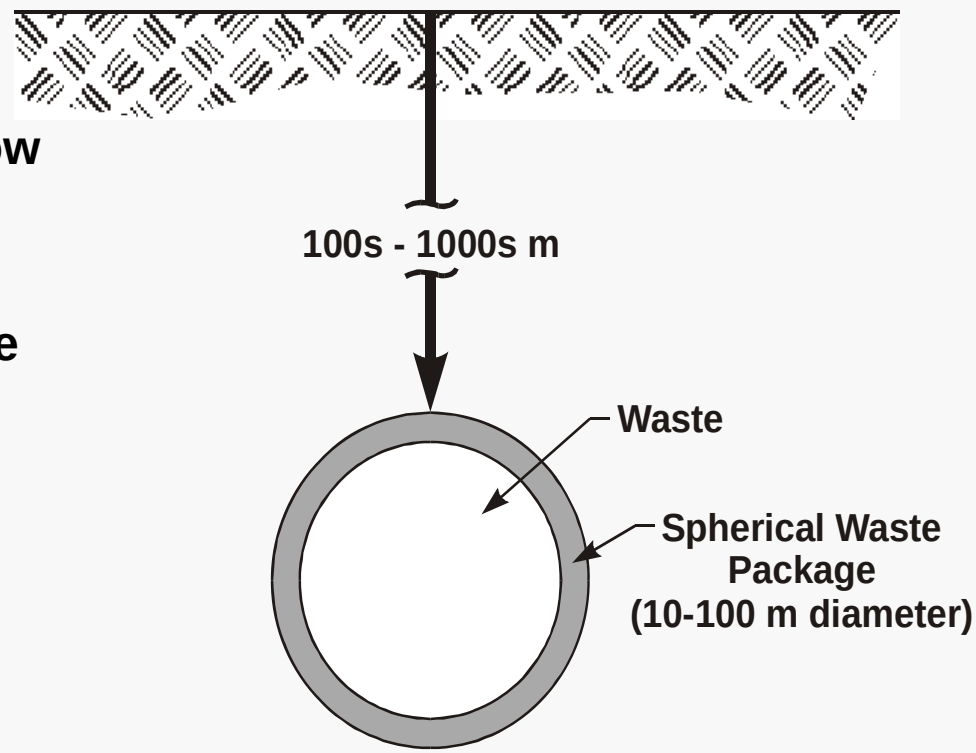
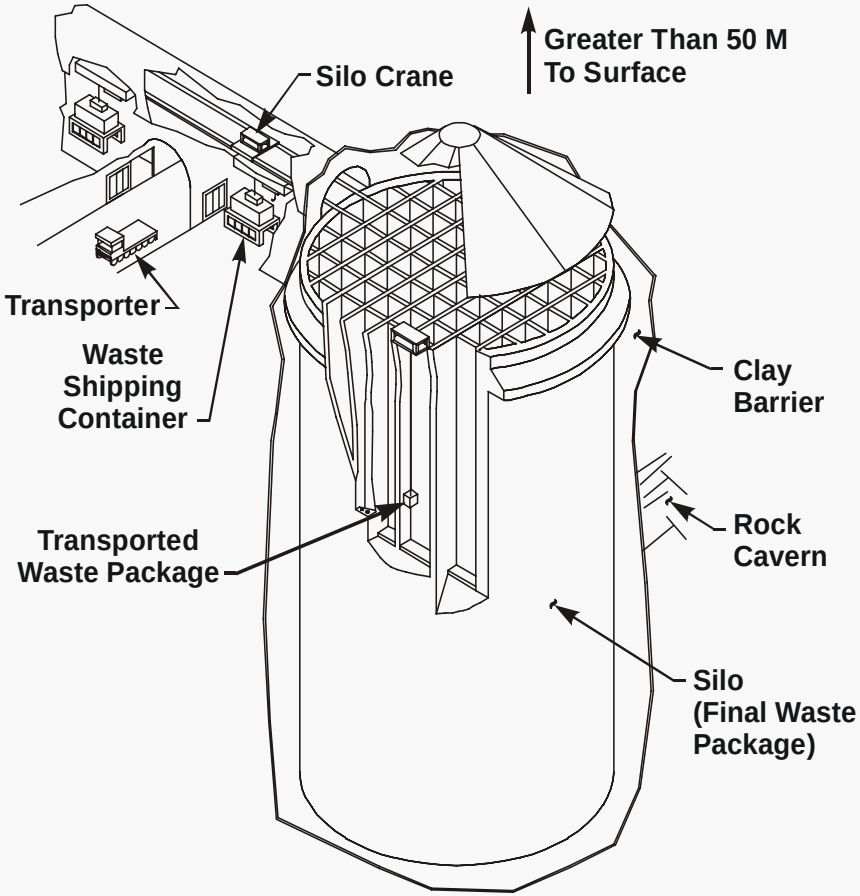
- **Maximize performance**
  - **Minimum water flow through waste package**
  - **Allow large high-performance waste package**
- **Minimize cost**
  - **Minimum mining**
  - **Minimize waste package cost per unit volume**



Idealized Low-Heat Radionuclide Repository

Silo for Low-Heat Waste Package

- **Candidate wastes**
  - **Recovered uranium**
  - **SNF clad**
  - **Other low-heat wastes**
- **"Silo" size determined by long-term heat load**
- **Option for short-term cooling (pipes in wall that are later closed)**



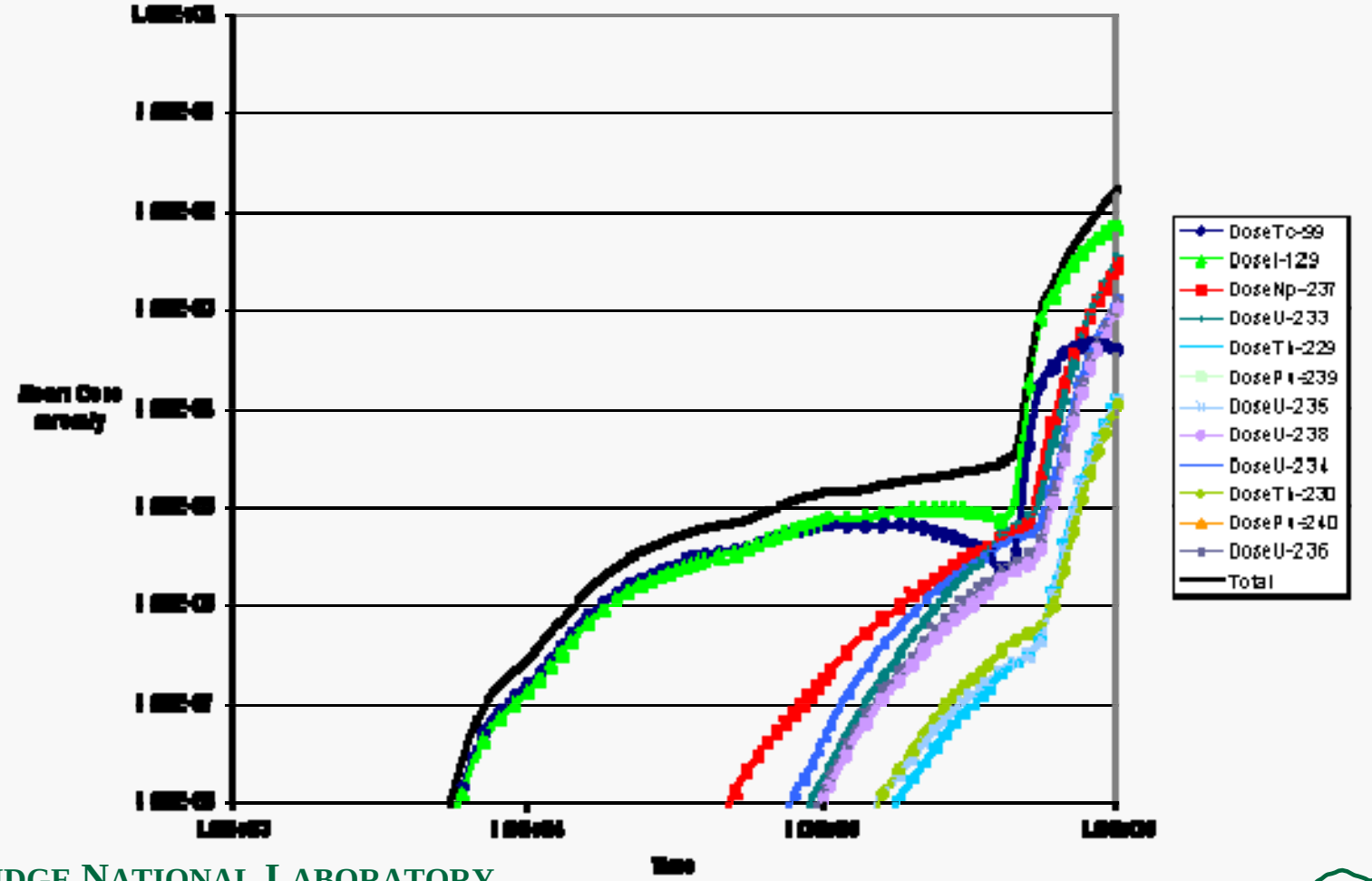
Operating Swedish SFR Silo for Low and Intermediate Wastes Under the Baltic Sea

ORNL DWG 89C-1100

Long-Lived Radionuclides that Control Repository Performance

YM Radiation Exposure Versus Time

Only a Few Nuclides (^{99}Tc, ^{129}I, and ^{237}Np) Control Repository Risk



EPRI: Expected Radiation Exposure

Options for Very Long-Lived Wastes

Extreme Isolation; Technical and Regulatory Uncertainties

Borehole

- **Waste**
  - **Low heat, low-volume**
  - **^{99}Tc, ^{129}I, ^{237}Np**
- **Extreme depth**
- **Isolation Mechanism**
  - **Distance to biosphere**
  - **Environment with no water movement**
  - **Salt water density gradient**

Subseabed

- **Waste**
  - **Low heat, low-volume**
  - **^{99}Tc, ^{129}I, ^{237}Np**
- **Double isolation**
  - **Geological**
  - **Ocean dilution**
- **Best option for ^{129}I?**
  - **Extreme isolation**
  - **Backup by ocean iodine dilution**

Repository Redox

Repository Redox Determines Which Radionuclides may Escape

Oxidizing

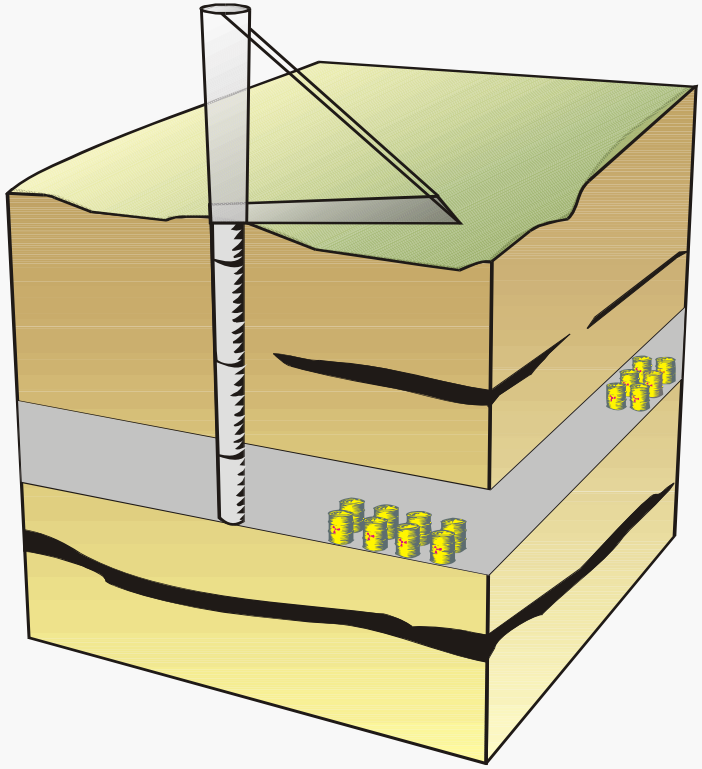
- **Radionuclides**
  - **Yucca Mountain**
  - **^{99}Tc, ^{129}I, ^{237}Np, ^{233}U**
- **Geologies**
  - **Tuff**
  - **Etc.**

Reducing

- **Radionuclides**
  - **Switzerland**
  - **^{14}C, ^{129}I, ^{36}Cl, ^{79}Se**
- **Geologies**
  - **Shale**
  - **Salt**
  - **Etc.**

Redox Option: Different Wastes to Different Repositories

Multiple Regulatory and Institutional Barriers



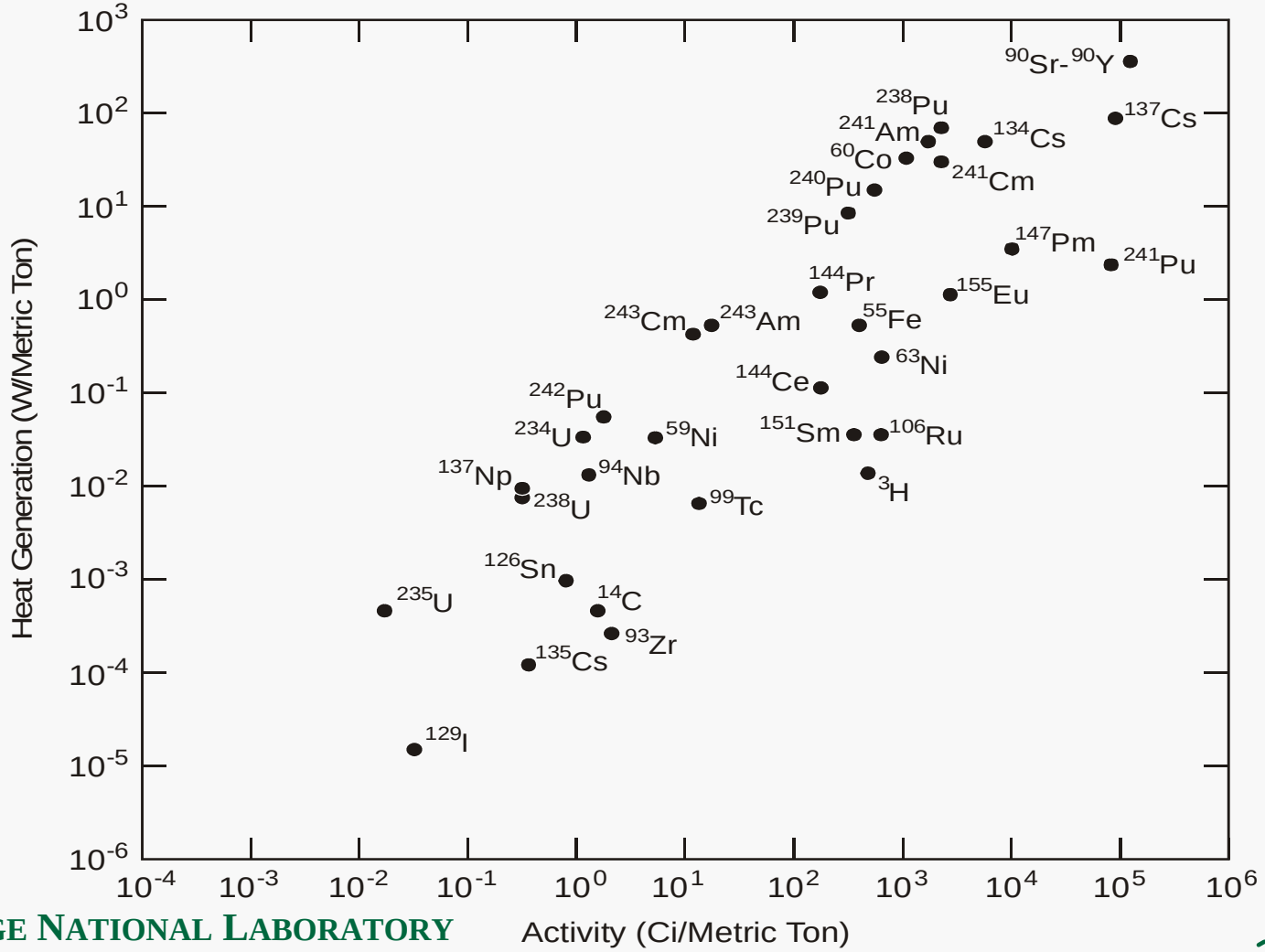
Conclusions

- **Reprocessing creates multiple waste forms and the potential for custom waste disposal of different waste forms**
  - **Potential for major cost savings**
  - **Potential for major reductions in repository risk**
- **Gains are independent of whether a single radionuclide is transmuted**
- **Full integration of reprocessing and repository design is required**

Backup Information

Heat Generation Rate and Activity

10-Year-Old PWR SNF with 33,000 MWd/t Burnup



Waste Form Characteristics

	SNF	U/Pu	HHRs	VLHR	MAs	Volatiles	Clad
Mass[a] (g)	1.427×10^{6}	9.576×10^{5}	4.132×10^{3}	3.030×10^{4}	1.192×10^{3}	7.206×10^{3}	2.918×10^{5}
Decay Heat[b] (watts)							
At 10 years	1.443×10^{3}	1.851×10^{2}	1.024×10^{3}	6.359×10^{1}	1.132×10^{2}	8.900×10^{0}	4.799×10^{1}
At 20 years	1.096×10^{3}	2.113×10^{2}	7.554×10^{2}	2.239×10^{1}	8.989×10^{1}	4.663×10^{0}	1.284×10^{1}
At 50 years	6.578×10^{2}	2.276×10^{2}	3.726×10^{2}	1.972×10^{0}	5.457×10^{1}	6.708×10^{-1}	3.051×10^{-1}
At 100 years	3.555×10^{2}	2.014×10^{2}	1.154×10^{2}	8.611×10^{-2}	3.858×10^{1}	2.668×10^{-2}	4.551×10^{-2}
At 1000 years	6.308×10^{1}	5.395×10^{1}	1.818×10^{-4}	2.353×10^{-2}	9.097×10^{0}	1.739×10^{-4}	1.531×10^{-2}

[a]Excludes oxygen in fuel; [b]Time after SNF discharge with reprocessing 5 years after reactor discharge

Biography: Charles Forsberg

Dr. Charles Forsberg is a Corporate Fellow at Oak Ridge National Laboratory, a Fellow of the American Nuclear Society, 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 and hydrogen production. He received the American Nuclear Society special award for innovative nuclear reactor design and the Oak Ridge National Laboratory Engineer of the Year Award. Dr. Charles Forsberg earned his bachelor's degree in chemical engineering from the University of Minnesota and his doctorate in Nuclear Engineering from MIT. After working for Bechtel Corporation, he joined the staff of Oak Ridge National Laboratory, where he is the Senior Reactor Technical Advisor. Dr. Forsberg has been awarded 10 patents and has published over 200 papers in advanced energy systems, waste management, and hydrogen futures.