Geological Repositories

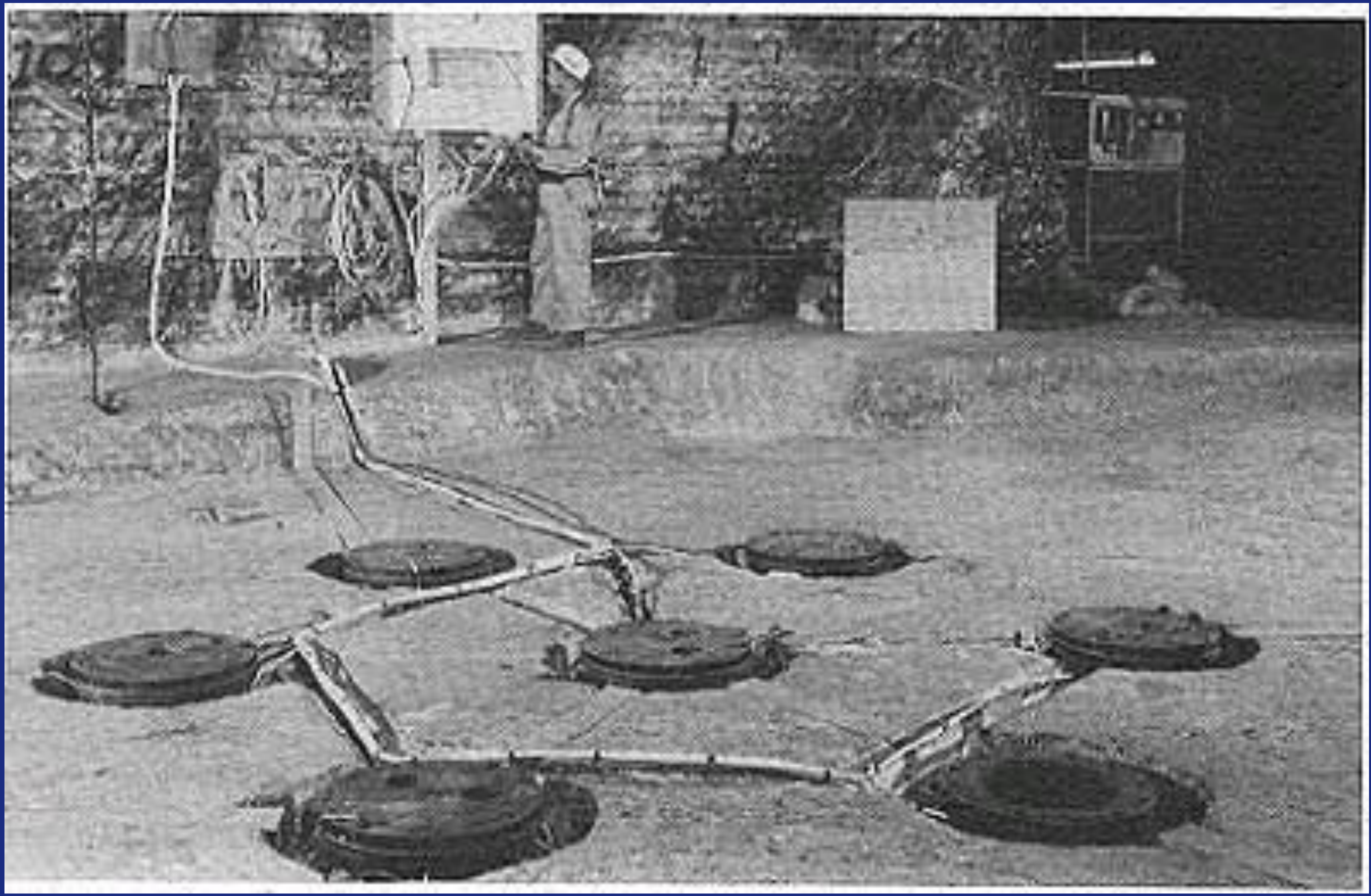
Michael Voegele

Need for Repositories

- Commercial nuclear development followed Eisenhower's “Atoms for Peace” speech.
- By the mid-1950s, the United States had made a decision to take naval nuclear reactor technology and apply it to the commercial generation of electrical power using civilian owned and operated reactors.
- The United States’ first commercial nuclear power plant was at Shippingport, in Pennsylvania.
- At the time this decision was made, the United States was reprocessing nuclear fuel materials.

Need for Repositories

- The National Academy of Sciences was asked in 1955 for a recommended solution to the problem of what to do with the wastes from reprocessing the civilian spent nuclear fuel.
- These reprocessing wastes were liquids and were both radioactive and chemically hazardous.
- The National Academy of Sciences noted in 1957 that "Disposal in cavities mined in salt is suggested as the possibility promising the most practical immediate solution of the problem.



The Lyons salt mine and the AEC's demonstration project in the late 1960's.
http://www.kgs.ku.edu/Publications/Bulletins/227/12_six.html

National Academy Report (1957): *The Disposal of Radioactive Waste on Land.*

The Committee is convinced that radioactive waste can be disposed of safely in a variety of ways and at a large number of sites in the United States. It may require several years of research and pilot testing before the first such disposal system can be put into operation.

Reality

Lyons KA failed early 70s

1975-76: ERDA proposed an ambitious plan – siting and development of as many as 6 repositories. First two in salt to begin pilot-scale operation by 1985. The next four in other rock types, notably shale and granite. Site investigations proposed for 36 states caused much turmoil.

International Consensus on Repository Disposal

- "from an ethical standpoint, including long-term safety considerations, our responsibilities to future generations are better discharged by a strategy of final disposal than by reliance on stores which require surveillance, bequeath long-term responsibilities of care, and may in due course be neglected by future societies whose structural stability should not be presumed."

The Environmental and Ethical Basis of Geological Disposal of Long-Lived Radioactive Wastes, OECD Nuclear Energy Agency (1995)

Moving Forward with Geological Disposal of High-Activity Radioactive Waste.

- “A geological disposal system provides a unique level and duration of protection for high-activity, long lived radioactive wastes.

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- “A geological disposal system provides a unique level and duration of protection for high-activity, long lived radioactive wastes. The concept takes advantage of the capabilities of both the local geology and the engineered materials to fulfill specific safety functions in complementary fashion, providing multiple and diverse barrier roles.”

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A Collective Statement by the NEA Radioactive Waste Management Committee (RWMC). OECD 2008; NEA no. 6433

Multiple barrier concept – engineered components in concert with geology

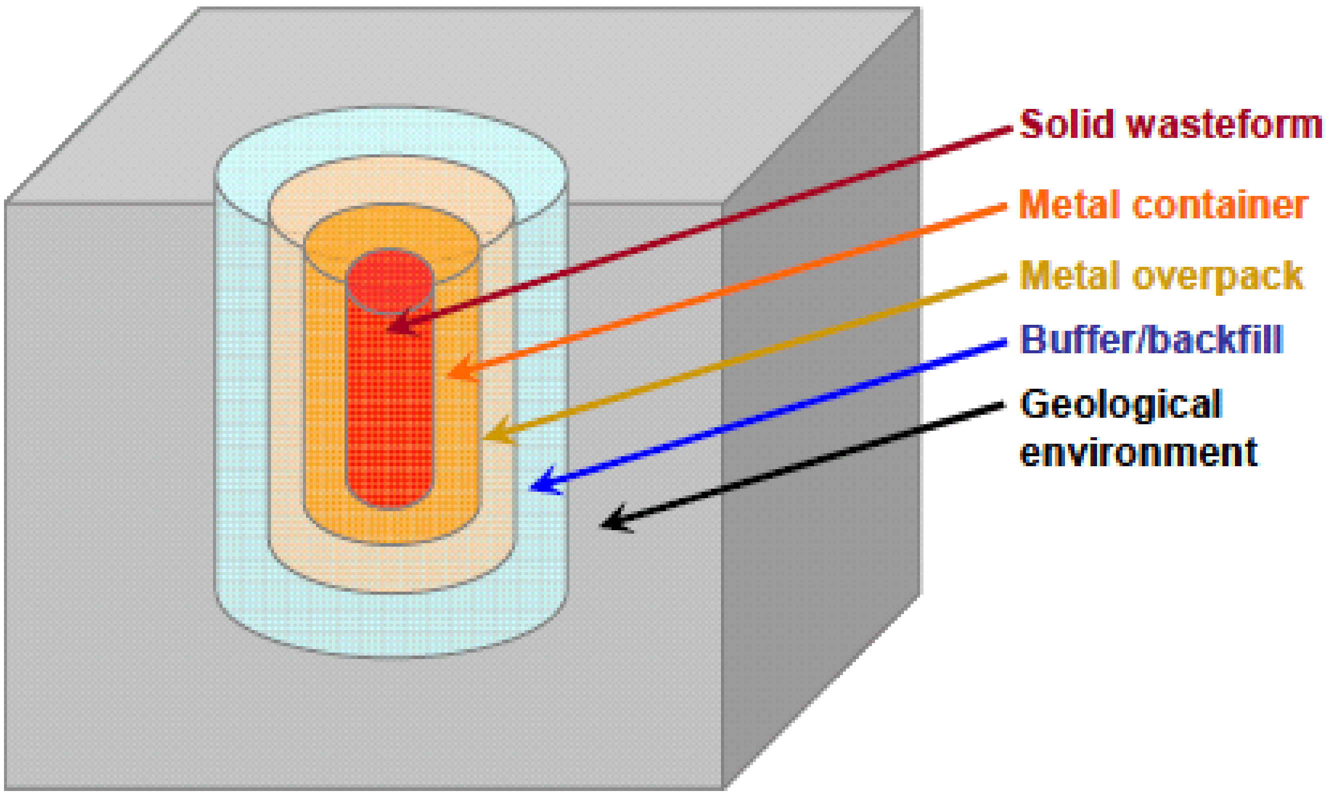
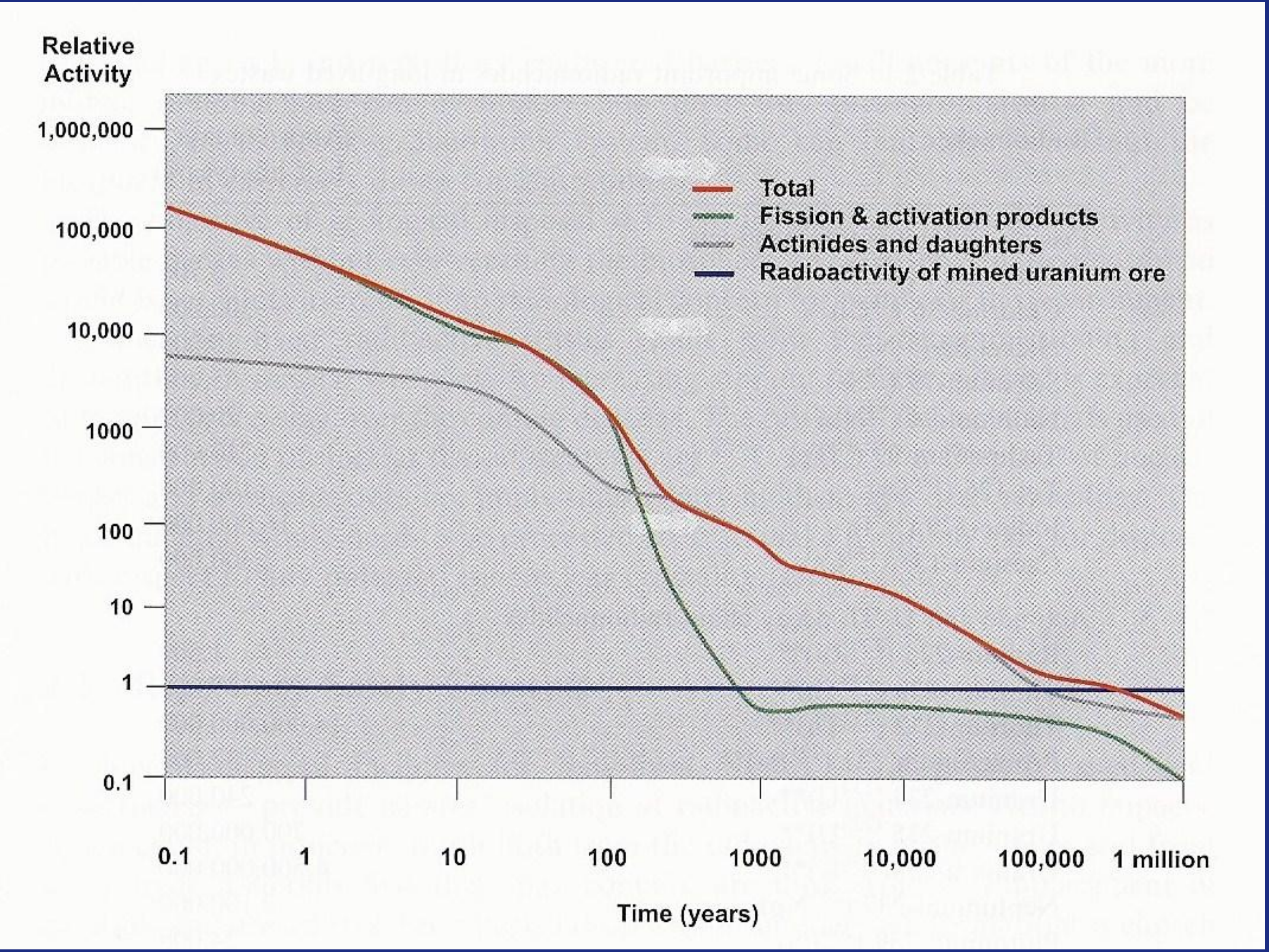


Image: Baldwin, T, Chapman, N, and F Neall 2008. Geological Disposal Options for High-Level Waste and Spent Fuel. Report for the UK Nuclear Decommissioning Authority



Chapman and McCombie, Principles and Standards for the Disposal of Long Lived Radioactive Wastes. 2003

U.S. Commitment to Repository Disposal*

- 1957 NAS Recommendation
  - Dealt with reprocessing wastes
- 1980 Waste Confidence Rule
  - Affirmed that there would be a repository
- 1980 DOE EIS on Management of Commercial Radioactive Wastes
  - R.O.D. - Least risk to mankind is from repository
- 1982 Nuclear Waste Policy Act
  - Directed two repositories (no one state would take all of the wastes)

U.S. Commitment to Repository Disposal*

- 1982 Nuclear Waste Policy Act
  - Allowed Monitored Retrievable Storage facility
- 1987 Nuclear Waste Policy Amendments Act
  - Repudiated a commitment that allowed NWPA to pass
- 1992 WIPP Land Withdrawal Act
  - Allowed TRU disposal but prohibited HLW and SNF
- 2002 H. J. Res. 87 [107th]: Yucca Mountain Development resolution
  - …. That there hereby is approved the site at Yucca Mountain, Nevada, for a repository, …

U.S. Repository Laws and Regulations

- Nuclear Waste Policy Act, as Amended
  - HLW, SNF, and Defense Wastes
- WIPP Land Withdrawal Act
  - Transuranic Wastes
- Energy Policy Act of 1992
- Allowable Releases and Compliance
  - 40 CFR Part 191, 40 CFR Part 197
- Site Screening
  - 10 CFR Part 960; 10 CFR Part 963
- Repository Development
  - 10 CFR Part 60; 10 CFR Part 63

Geological Criteria for Repositories for High-Level Radioactive Waste

- Geometrical and dimensional criteria:
  - sufficient depth
  - adequate room
  - information on the geometry and physical, chemical, and mineralogical properties available in advance of development of the site.

Geological Criteria for Repositories for High-Level Radioactive Waste

- Long-term stability criteria:
  - structurally stable geological block
  - not near a tectonic boundary
  - avoid faults along which rupture could occur
  - avoid areas with abnormally high geothermal gradients or with evidence of relatively recent volcanic activity
  - mechanical properties should assure stability during operation

Geological Criteria for Repositories for High-Level Radioactive Waste

- Hydrological criteria:
  - fluid transport should not move hazardous material to the biosphere in amounts and rates above prescribed limits
  - system should be capable of being sealed when the repository is closed
  - the geological record should support predictions favorable for long-term hydrological isolation of the repository site in a perturbed geological environment

Geological Criteria for Repositories for High-Level Radioactive Waste

- Geochemical criteria:
  - heat and radiation should not produce physical and chemical reactions in the rock that would compromise containment
  - conditions should minimize the rate of dissolution of the waste form
  - water in the repository, if present, should not react to increase permeability
  - properties should limit mobility of radionuclides and delay or prevent their migration to the biosphere

Geological Criteria for Repositories for High-Level Radioactive Waste

- Geo-economic criteria:
  - no area with record of resource extraction should be considered as a geological site for radioactive waste

Geological Criteria for Repositories for High-Level Radioactive Wastes: National Research Council, 1978

Performance after permanent closure

- The geologic repository is required to:
  - Limit radiological exposures to the reasonably maximally exposed individual
  - Limit releases of radionuclides to protect ground water; and
  - Limit radiological exposures in the event of human intrusion
- Demonstrating compliance requires a performance assessment to quantitatively estimate radiological exposure
  - Risk informed / probability based

Performance assessment.

- Systematic analysis that identifies the features, events, and processes that might affect performance of the geologic repository;
- Examines their effects on performance; and
- Estimates the radiological exposures

- Uncertainties are addressed by requiring the use of a multiple barrier approach;
  - Specifically, an engineered barrier system is required in addition to the natural barriers provided by the geologic setting.

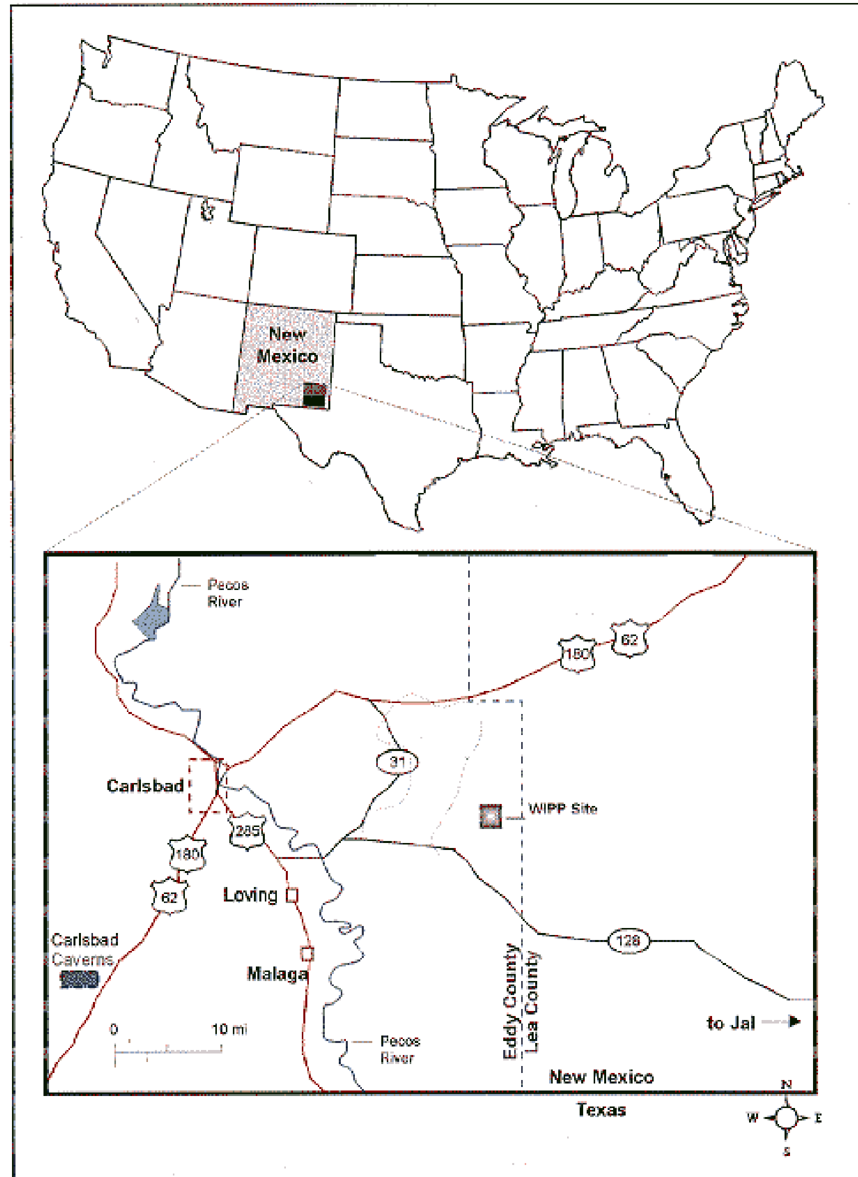
Need to understand long-term geological processes at a disposal site

Wisconsin Ice Sheet ca 18,000 BP

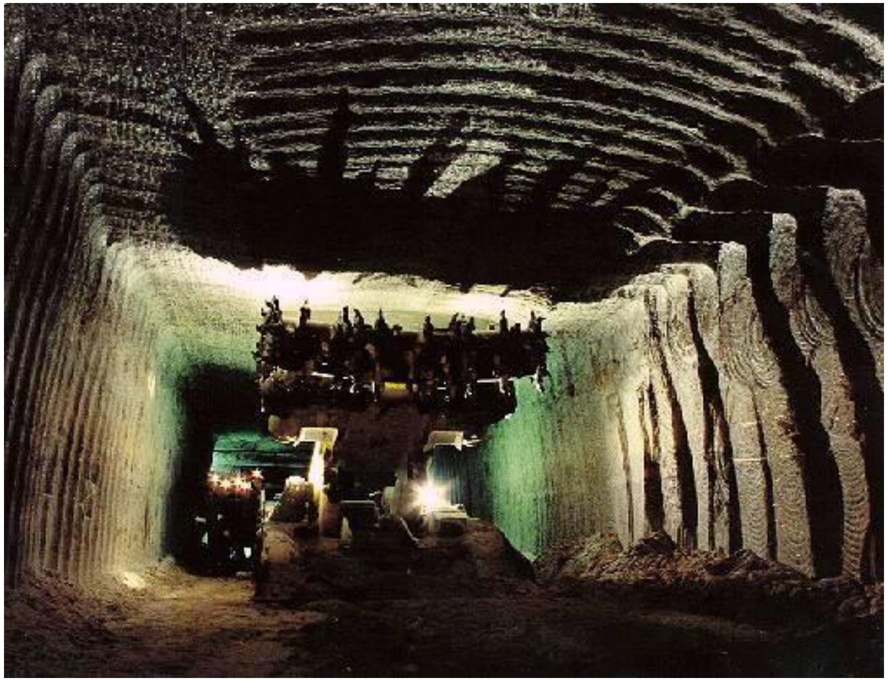
- Tectonics – uplift, subsidence
- Earthquakes and faulting
- Igneous activity – volcanoes, magma intrusions
- Climate change – precipitation, glaciations
- Denudation – erosion processes
- Chemical alteration of rocks – water-rock interaction
- Groundwater flow

WIPP

- The Waste Isolation Pilot Plant (WIPP) is designed as a repository for defense-related transuranic (TRU) waste.
- WIPP is the first mined deep geological repository in the world to receive waste. (The first shipment was received on Mar 26, 1999.)
- WIPP is in bedded salt approximately 658m below the ground surface near Carlsbad, New Mexico.



Advantages of salt



- Found in stable geological areas -- very little earthquake activity.
- Absence of flowing fresh water. (If water were present, salt would have dissolved.)
- Relatively easy to mine.
- Rock salt heals its own fractures because of its plastic quality. Salt will slowly move in to fill mined areas and seal radioactive waste from the environment.

Extensive underground testing was conducted at the WIPP – reaction of salt to heating, rock mechanics studies, hydrogeologic studies

Underground Research Laboratories -- examples

- (HADES) in the Boom Clay, Belgium
- Bure in the Callovo-Oxfordian clay, France
- Grimsel in the granitic rock of the Aar Massif, Switzerland
- Hard Rock Laboratory (HRL) at Äspö, Sweden
- Horonobe in Koetoi and Wakkanai argillaceous formations, Japan

Current Status HLW Repositories

- Sweden – LA submitted for Forsmark
- Finland – site selected at Olkiluoto
- Great Britain – Generic Safety Case
- Yucca Mountain
  - June 3, 2008 DOE submits LA
  - Sept 8, 2008 NRC dockets LA
  - Mar 3, 2010 DOE moves to withdraw LA
  - June 29, 2010 ASLB denies withdrawal
  - July 1, 2011 NRC must act

Observations on the Future*

- U.S. repository program was built around Yucca Mountain
  - WAC evolved with Yucca Mountain designs
  - Storage concepts (and TADs) were compatible with disposal because of ramp access at Yucca Mountain
  - Open nature of the Yucca Mountain repository allowed for storage and cooling before closure
  - Retrievability is desirable to not limit future options
  - State prohibitions on nuclear development require the fuel cycle to be closed

*

Table 7-2. Relative Attributes of Alternative Media for Geologic Disposal (BMWI 2008; Stenhouse et al. 2010, Figure 7-5; Hansen et al. 2010b, Table 1).

Characteristic	Salt	Clay/Shale	Crystalline Rocks	
			Geologic	Borehole
Media Property				
Thermal conductivity	High	Low	Moderate	Moderate
Heat resistance	High	Low	High	High
Permeability	Practically impermeable	Very low to low	Low (unfractured) High (fractured)	Very low
Sorption behavior	Very low	Very high	Moderate	Moderate
Dissolution	Very high	Very low	Very low	Very low
Chemical	Reducing	Reducing	Reducing	Reducing
Deformation behavior	Visco-plastic	Plastic	Brittle	Brittle
Strength	Medium	Low to medium	High	High
In-situ stress	Isotropic	Anisotropic	Anisotropic	Anisotropic
Homogeneity	High	Moderate	Moderate	Moderate
Location dependent				
Geologic stability in US	High	High	High	High
Availability in US	Wide	Wide	Medium	Wide
Resource coexistence	High	Medium	Low	Low
Repository design				
Mining experience	High	Low	High	Low
Cavity stability	Self-support on decade scale	Reinforcement required	High (unfractured) Low (fractured)	Low to Medium at great depth
Repository seals	Needed	Needed	Needed	Needed
Waste package	Minimal	Minimal	Needed	Minimal

Key for attributes	Favorable	Average	Unfavorable

From: Rechard, et al. Basis for Identification of Disposal Options for Research and Development, *March 2011* FCRD-USED-2011-000071 SAND2011-3781P

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The Yucca Mountain Repository SEIS Evaluated Several Inventory Cases

The Proposed Action is 70,000 MTHM

The modules are all CSNF wastes, and GTCC wastes

Case A represents an inventory without recycling

Case B represents an inventory that assumes recycling (GNEP alternative)

INVENTORIES

Proposed Action

- 63,000 MTHM of commercial spent nuclear fuel and a very small quantity of commercial high-level radioactive waste
- 2,333 MTHM of DOE spent nuclear fuel
- 4,667 MTHM (9,334 canisters) of DOE high-level radioactive waste

Inventory Module 1 Case A

- 130,000 MTHM of commercial spent nuclear fuel
- 2,500 MTHM of DOE spent nuclear fuel
- 36,000 canisters of DOE high-level radioactive waste

Inventory Module 1 Case B

- 63,000 MTHM of commercial spent nuclear fuel
- 2,500 MTHM of DOE spent nuclear fuel
- 36,000 canisters of DOE high-level radioactive waste
- 13,400 to 29,000 canisters of commercial high-level radioactive waste (from recycling 67,000 MTHM of commercial spent nuclear fuel)

Inventory Module 2 Case A

- 130,000 MTHM of commercial spent nuclear fuel
- 2,500 MTHM of DOE spent nuclear fuel
- 36,000 canisters of DOE high-level radioactive waste
- Approximately 36,000 cubic meters (1.3 million cubic feet) of Greater-Than-Class-C or Greater-Than-Class-C-like low-level radioactive waste

Inventory Module 2 Case B

- 63,000 MTHM of commercial spent nuclear fuel
- 2,500 MTHM of DOE spent nuclear fuel
- 36,000 canisters of DOE high-level radioactive waste
- 13,400 to 29,000 canisters of commercial high-level radioactive waste (from recycling 67,000 MTHM of commercial spent nuclear fuel)
- Approximately 176,000 cubic meters (6.2 million cubic feet) of Greater-Than-Class-C or Greater-Than-Class-C-like low-level radioactive waste (most of which would result from the recycling effort)

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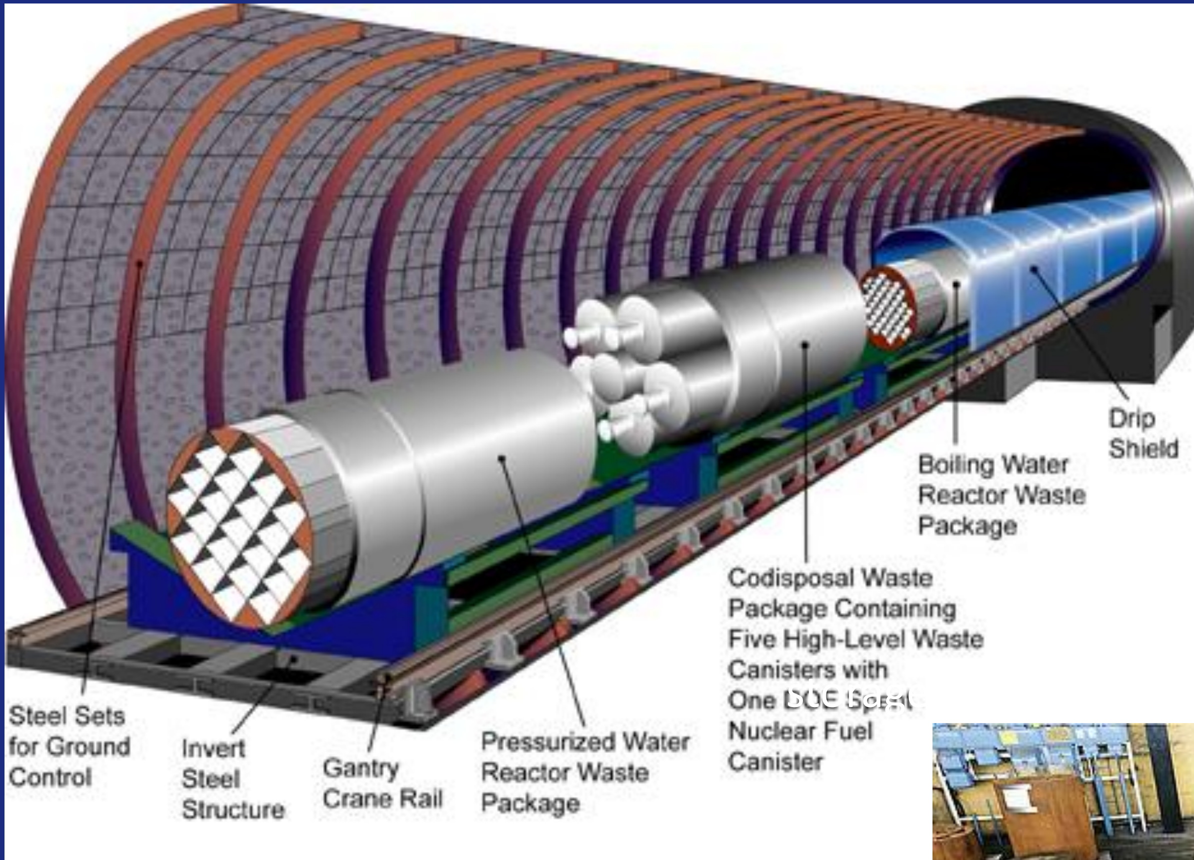
Waste Packages must accommodate a number of fuel assemblies or canisters



Copper Swedish waste packages

Pre license application Yucca Mountain waste package designs

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Waste Package Design	Approximate Percentage of Waste Packages	Approximate Number of Waste Packages	Limit to Four Assemblies
21 PWR AP	38%	4180	21945
21 PWR CR	1%	110	578
12 PWR Long	2%	220	660
44 BWR	25%	2750	15125
24 BWR	1%	110	330
	67%		
5 DHLW SNF Short	14%	1540	1540
5 DHLW SNF Long	15%	1650	1650
2 MCO 2 DHLW Long	1%	110	110
Naval Short	2%	220	220
Naval Long	1%	110	110
	33%	11000	42268

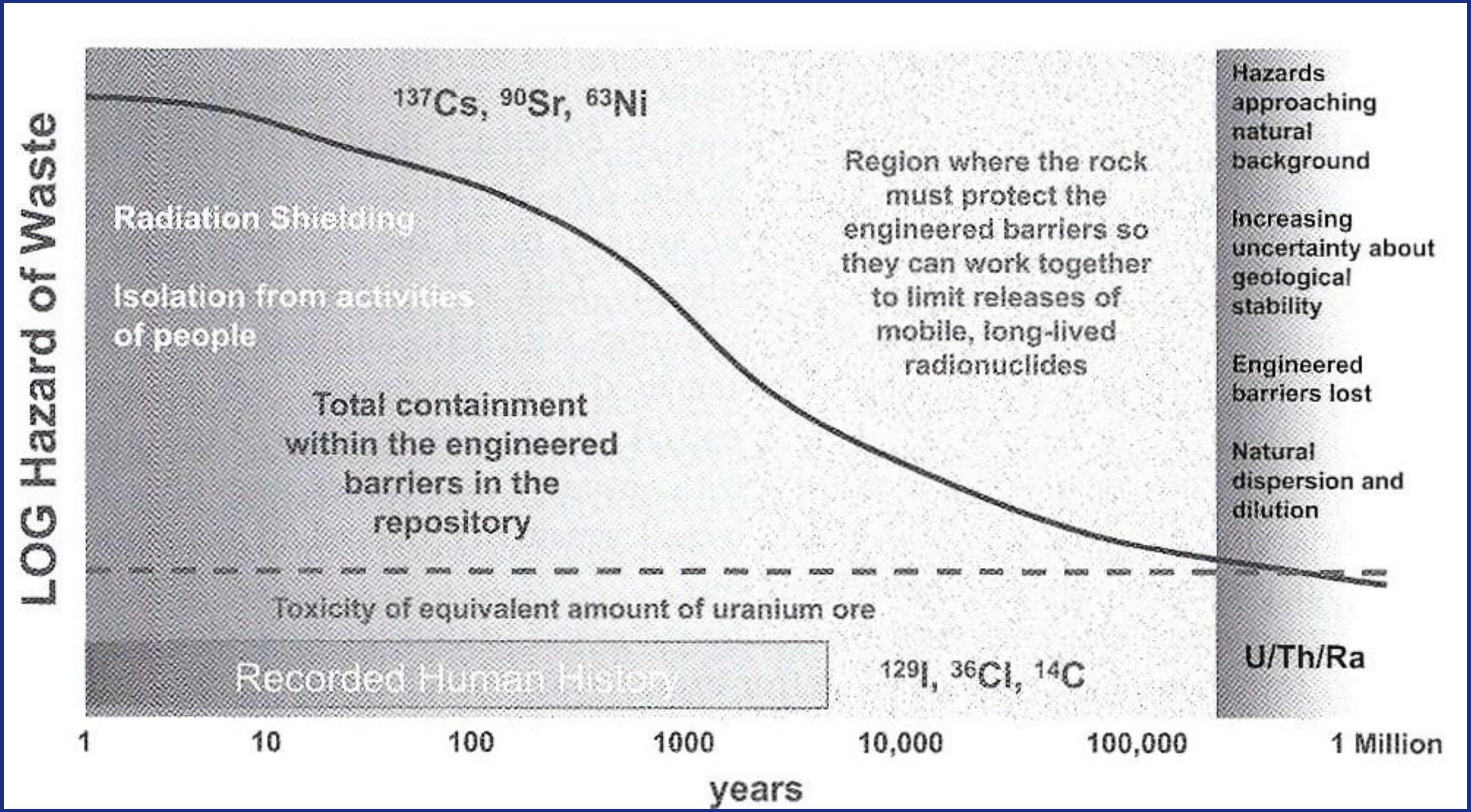
Image from: http://www.sandia.gov/LabNews/LN04-09-99/wipppix.html

U.S. – National Academy committee met in 1955-56 and issued a report in 1957: *The Disposal of Radioactive Waste on Land.*

Harry Hess, Chairman; John Adkins, William E. Benson, John C. Frye, William B. Heroy, M. King Hubbert, Richard J. Russell, Charles V. Theis

an amazing group – for example:

AGU awards the Harry H. Hess Medal
GSA presents the John C. Frye Environmental Geology Award
AGI presents the William B. Heroy Jr. Award
NGWA presents the M. King Hubbert Award
AAG presents the Richard J. Russell Coastal Geomorphology Award
AIH presents the C.V. Theis Award



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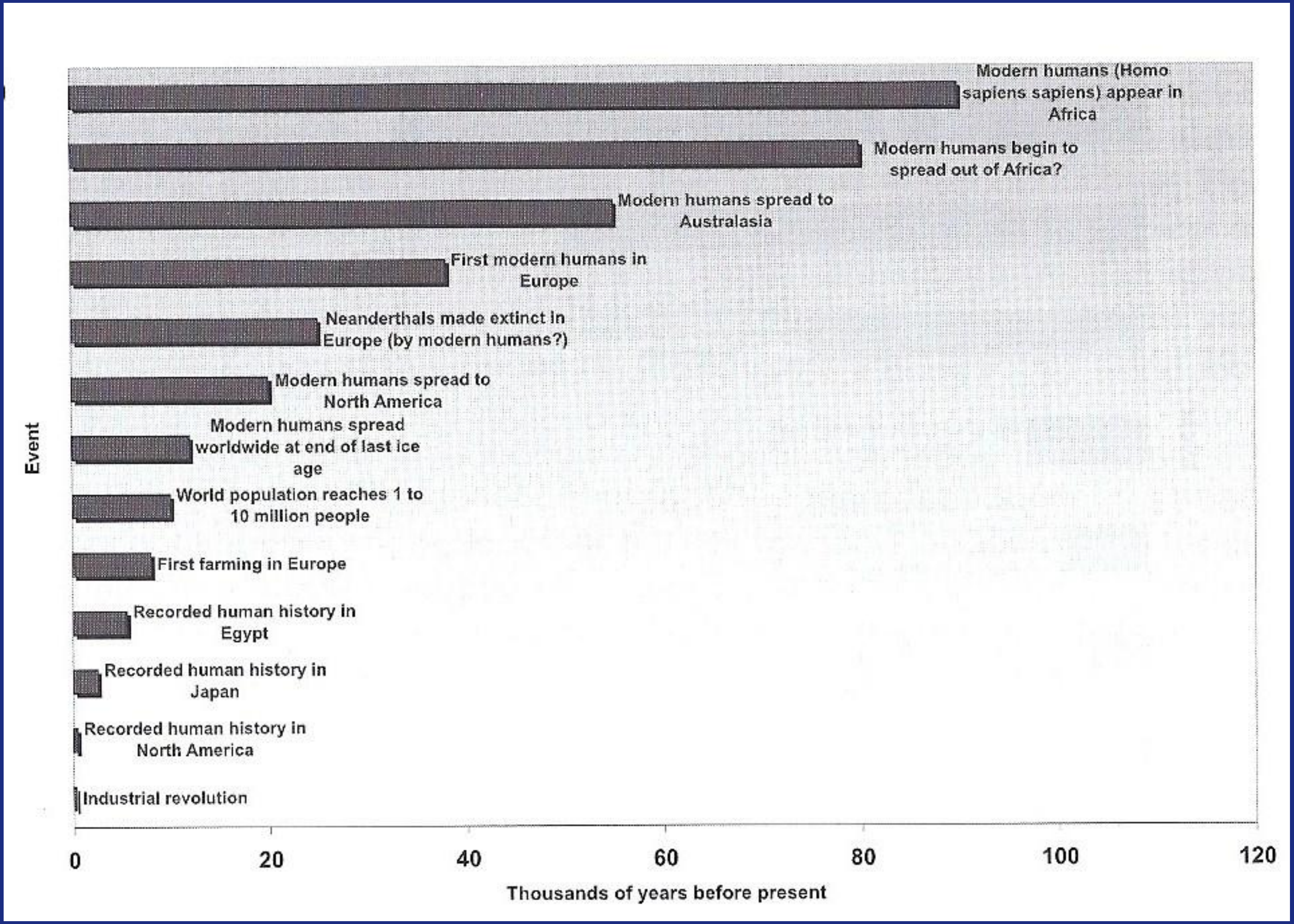

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