International Spent Nuclear Fuel Options

ENG 471 Seminar

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ILLINOIS

Interactive Slides

The web-interactive first half of the talk can be found at:

https://katyhuff.github.io/2017-09-27-eng471

Outline

1. Introduction
   - Nuclear Nations
   - Spent Fuel Inventory
2. Spent Fuel Options
   - Long-Term Storage
   - Reprocessing
   - Deep Geologic Disposal

Nuclear Power Nations

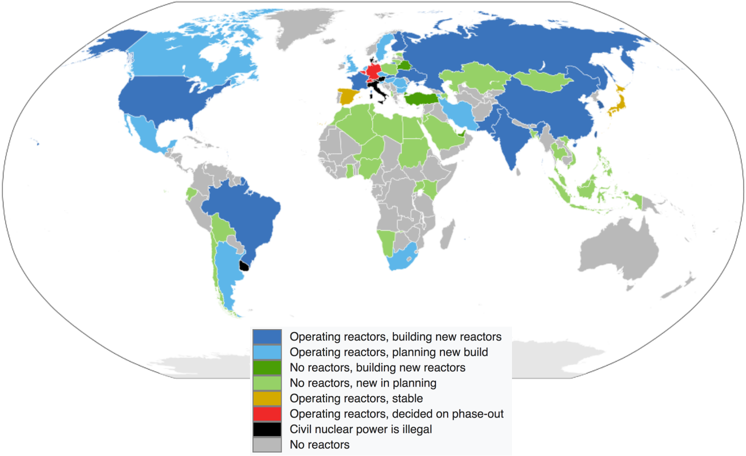


Figure 1: Nuclear power status of all nations [12].

Nuclear Weapons Nations

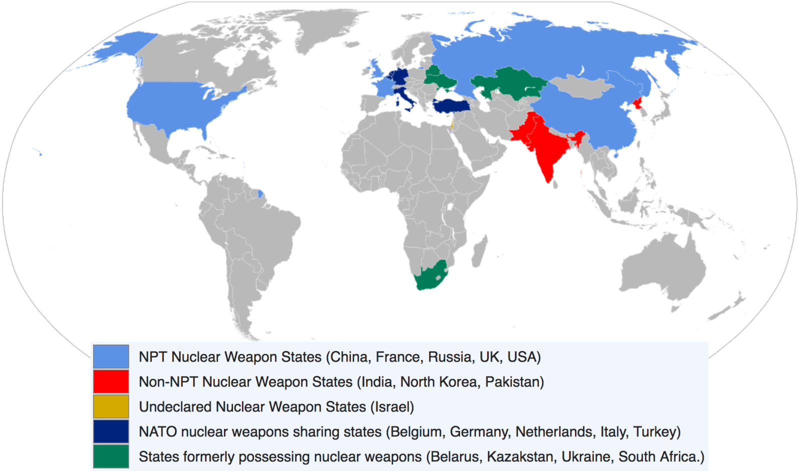
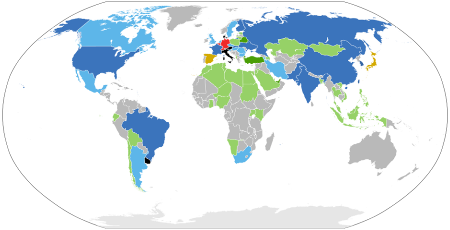
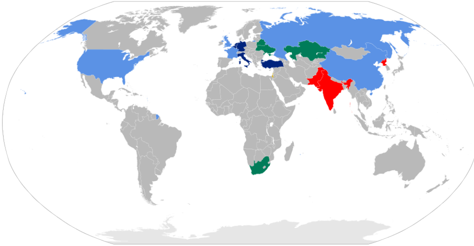


Figure 2: Nuclear weapons status of all nations [12].

Power vs. Weapons





International Reactors

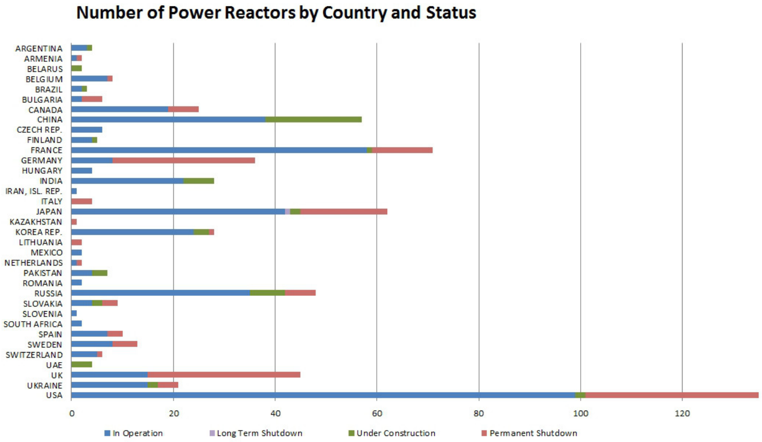


Figure 3: Nuclear reactors internationally, replicated from [8].

Nuclear Capacity

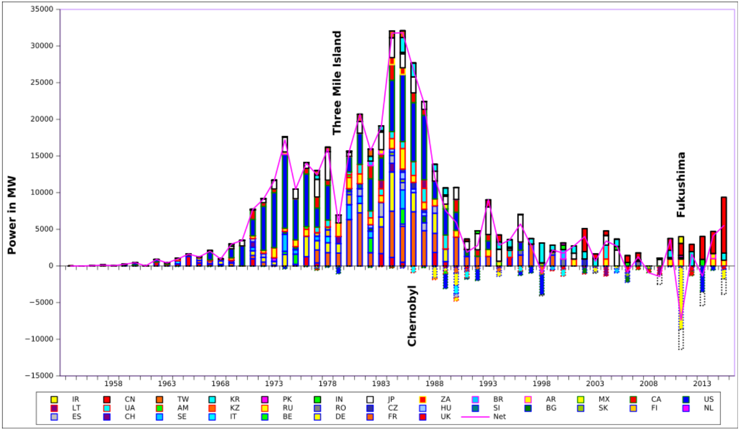


Figure 4: Nuclear power deployments as a function of time [15].

Spent Fuel Inventory

Radioactive Waste Volumes

Type	In storage (m^3)	In disposal (m^3)	% in disposal
VLLW	2,356,000	7,906,000	77%
LLW	3,479,000	20,451,000	85%
ILW	460,000	107,000	19%
HLW	22,000	0	0%

Table 1: Solid radioactive waste volumes worldwide, IAEA estimate 2016. [**?**]

VLLW, LLW, ILW

Liquid

Must be solidified or, must be packed in absorbant package 2x liquid volume. (i.e. decontamination solutions, liquid scintillators, ion-exchange fluids, etc.)

Wet Solid

Greater than 1% liquid, but primarily solid (i.e. filters).

Dry Solid

Less than 1% liquid (i.e. trash, swipes, clothes, tools, etc.)

Spent Fuel Inventory

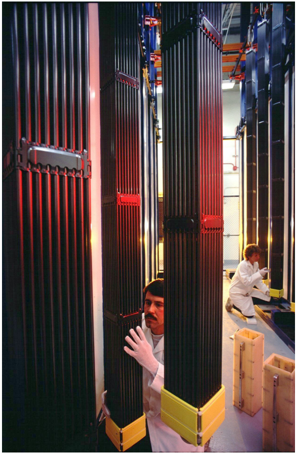


Figure 5: Spent nuclear fuel from conventional power reactors is in the form of uranium oxide fuel rods [?].

Spent Fuel

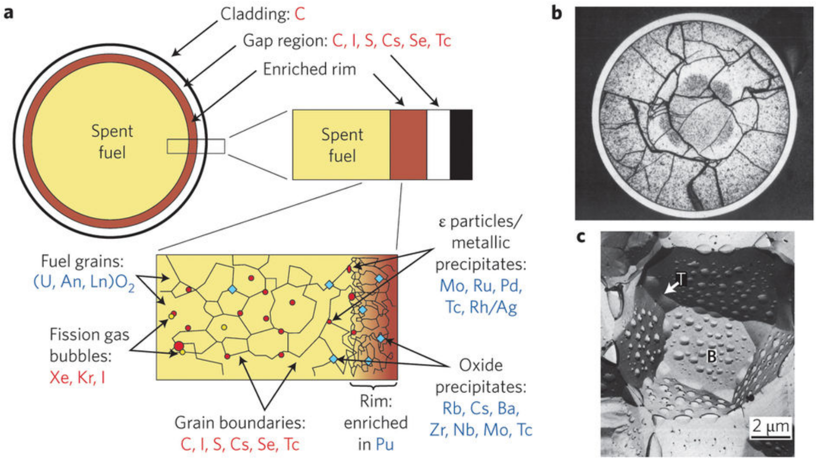


Figure 6: Microstructure of spent fuel and the distribution of fission products and actinides after irradiation in a reactor. From [?].

Spent Fuel Inventory

High Level Waste

- 300,000 metric tons worldwide [?]
- 90% in storage pools
- remainder in dry casks

Outline

Array of Possible Options

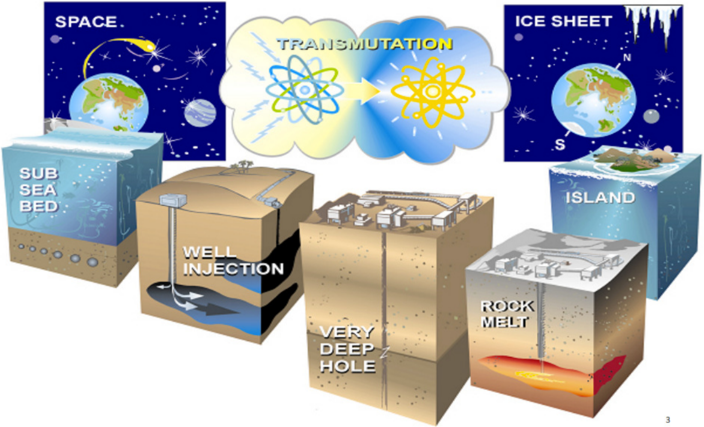


Figure 7: An array of options have been considered in the past [13].

VLLW, LLW, ILW

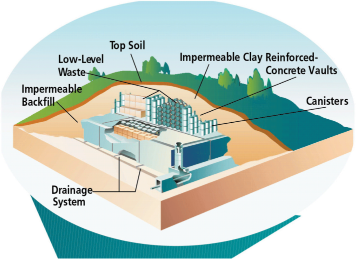


Figure 8: Design of a LLW repository.

Figure 9: Waste Control Specialists Low Level Waste Repository in Andrews County, Tx.

Spent Fuel Inventory

Figure 10: Spent fuel pools are at reactor sites and elsewhere [?].

Figure 11: Dry casks at reactor sites and elsewhere [10]

Reprocessing Waste

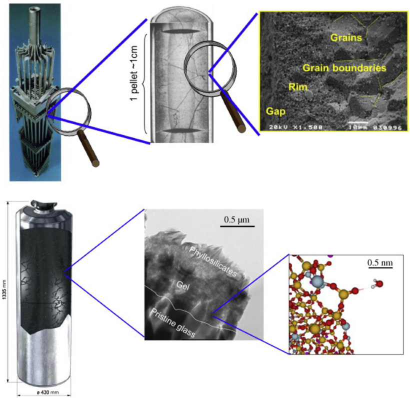


Figure 12: A comparison of uranium oxide and borosilicate glass waste forms [14].

Reprocessing Waste

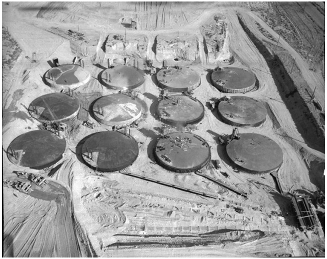


Figure 13: Liquid waste in steel or carbon steel tanks at Hanford and elsewhere[**?**].

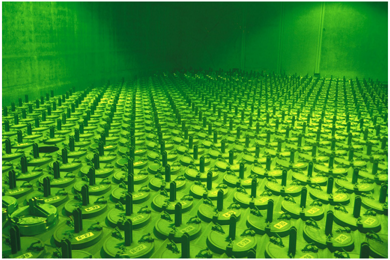


Figure 14: Vitrified glass logs at reprocessing facilities and elsewhere [5].

Reprocessing Capacity

Global reprocessing capacity is shown in Fig. 15.

	Thermal Reactor UNF	Fast Reactor UNF
Research/Pilot/Demonstration Reprocessing Facility	Japan (Tokai facility) China (at Lanzhou) France (Atalante) India (BARC, IGARC) Italy (at Rotondella) Belgium (Eurochemic facility) Germany (WAK/Karlsruhe) Russia (Khoplin, Bochvar) United Kingdom (Sellafield) United States (national laboratories)	Russia France Japan United Kingdom United States (Argonne National Laboratory and Oak Ridge National Laboratory)
Commercial Reprocessing Facility	France (Marcoule and La Hague facilities) United Kingdom (THORP and Magnox reprocessing facilities at Sellafield) Russia (RT-1 facility) United States (West Valley) India (Trombay, Tarapur, Kalpakkam)	France

Figure 15: [2].

MOX production

Global MOX production is shown in Fig. 16.

TABLE II: WORLDWIDE MOX FUEL FABRICATION CAPACITIES (tHM/YR) IN 2009 AND 2015

	2009	2015
France: MELOX	195	195
Japan: Tokai	10	10
Japan: Rokkasho	0	130
Russia: Mayak, Ozersk (pilot)	5	5
Russia: Zheleznogorsk (fast reactor fuel)	0	60
United Kingdom: Sellafield	40	0
Total for thermal reactors	**250**	**400**

Figure 16: [2].

Clay Disposal Environments

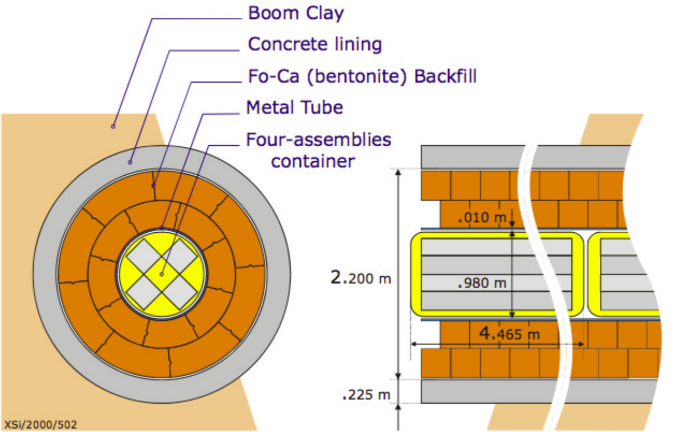


Figure 17: Belgian reference concept in Boom Clay [16].

Granite Disposal Environments

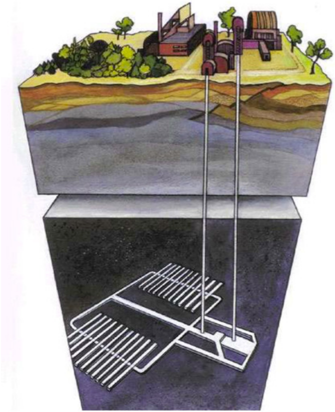


Figure 18: Czech reference concept in Granite [16].

Salt Disposal Environments

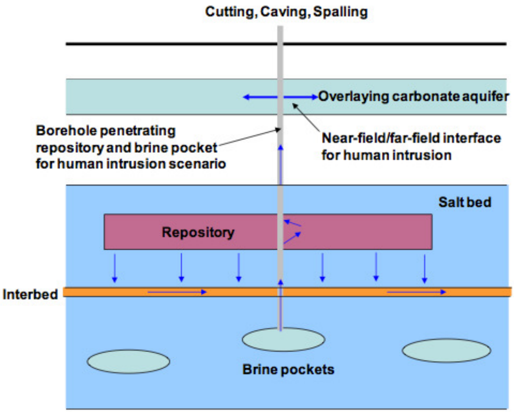


Figure 19: DOE-NE Used Fuel Disposition Campaign concept in Salt [4].

Deep Borehole Disposal Environment

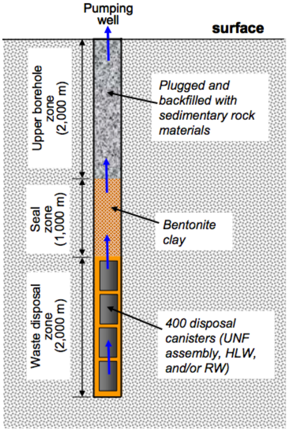
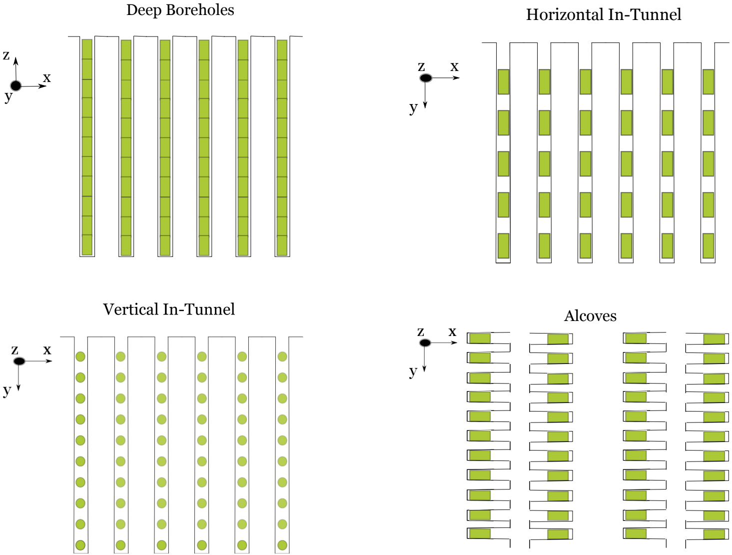


Figure 20: DOE-NE Used Fuel Disposition Campaign Deep Borehole concept [4].

Repository Layouts



All Disposal Environments

Features of Various Concepts

Feature	Clay	Granite	Salt	Deep Borehole
Hydrology				
Total Porosity [%]	34-60	0.1	0.5	0-0.5
Eff. Porosity [%]	0.5-5	0.0005	0.1	0.00005-0.01
Conductivity[m/s]	$10^{-11} - 10^{-9}$	$10^{-6} - 10^{-5}$	$10^{-12} - 10^{-10}$	$10^{-13} - 10^{-4}$
Fracturation	none	high	none	low at depth
Geochemistry				
Reducing	Near & Far Field	NF only	NF only	NF only
Oxidizing	none	Slight in FF	Slight in FF	Slight in FF
Salinity	higher at depth	higher at depth	high	high
pH	~ 7	≥ 7	≥ 7	~ 7
Design				
Waste Package	Steel, Cu	Steel, Cu	Steel	Steel,Cement
Buffer	-,Fo-Ca,Cement	Fo-Ca,Cement	Crushed Salt	-,Fo-Ca,Cement
Depth	100-500 m	100-500 m	100-500m	3-5km
Emplacement	Vert.,Horiz,Alcove	Vert.,Horiz.	Alcove	Vert.
Packages/Gallery	one, many	one, many	one, two	400
Thermal Behavior				
Buffer Limit [$^\circ C$]	100 (Fo-Ca)	100 (Fo-Ca)	180	100 (Fo-Ca)
Host Limit [$^\circ C$]	100 (alteration)	200 (cracking)	180 (brines)	none
Conductivity [$\frac{W}{m \cdot K}$]	$1 - 2$	$2 - 4$	~ 4	$2 - 4$
Coalesence	yes	no	yes	no

Repository Components

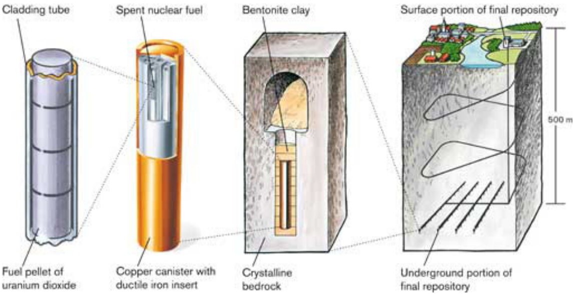
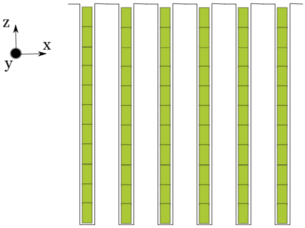


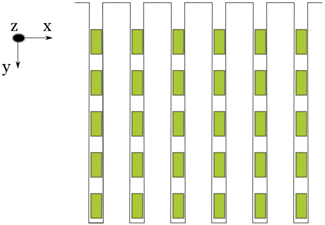
Figure 21: Geologic disposal systems typically employ engineered barrier systems as well as natural barrier systems. This is a Swedish concept in granite [1].

Repository Layouts

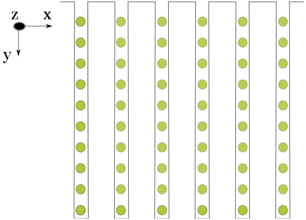
Deep Boreholes



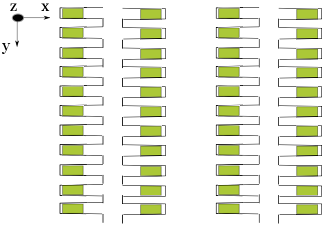
Horizontal In-Tunnel



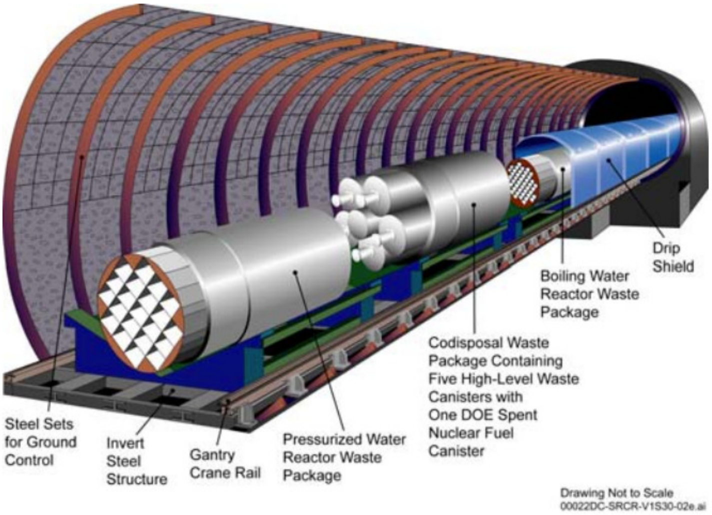
Vertical In-Tunnel



Alcoves



Unsaturated, Ventilated Concepts



Saturated , Enclosed Concepts

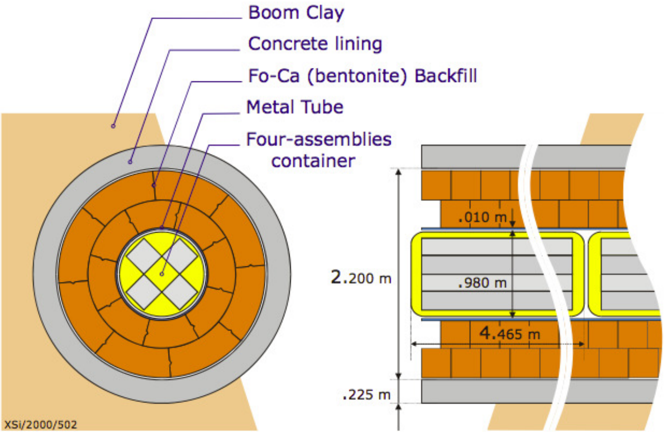


Figure 23: The Belgian reference concept in Boom Clay is backfilled very soon after waste emplacement without a ventilation period and is located below the water table [16].

Tuff (Yucca) Disposal Environments

Figure 24: Yucca Mountain is in southern Nevada [11].

Alternative Disposal Geology Options

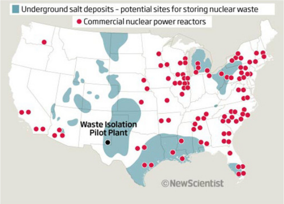


Figure 25: U.S. Salt Deposits, ref. [9].

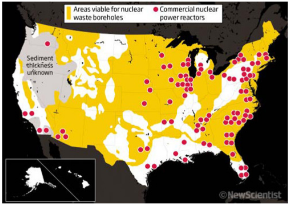


Figure 27: U.S. Crystalline Basement, ref. [9].

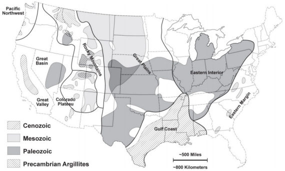


Figure 26: U.S. Clay Deposits, ref. [6].

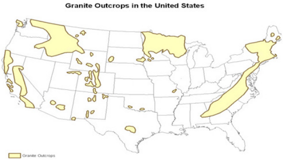


Figure 28: U.S. Granite Beds, ref. [3].

Clay Disposal Environments

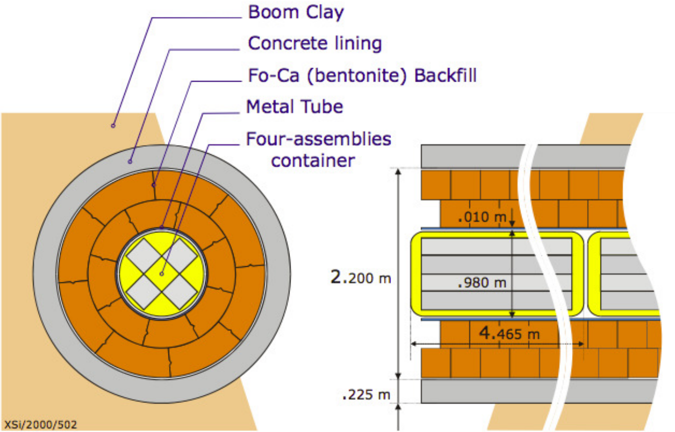


Figure 29: Belgian reference concept in Boom Clay [16].

Granite Disposal Environments

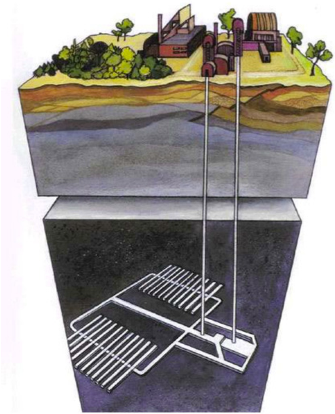


Figure 30: Czech reference concept in Granite [16].

Salt Disposal Environments

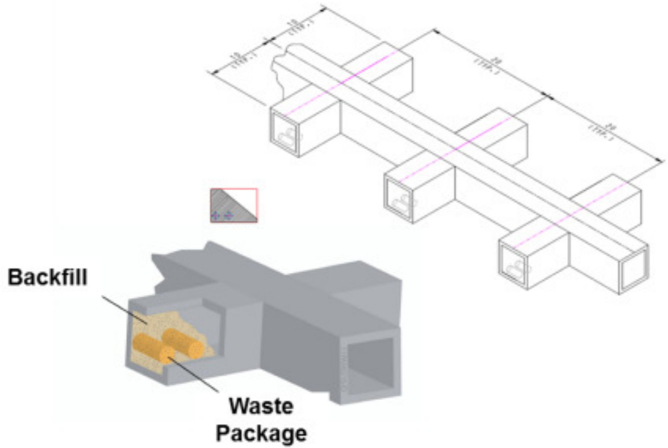


Figure 31: DOE-NE Used Fuel Disposition Campaign concept in Salt [7].

Salt Disposal Environments

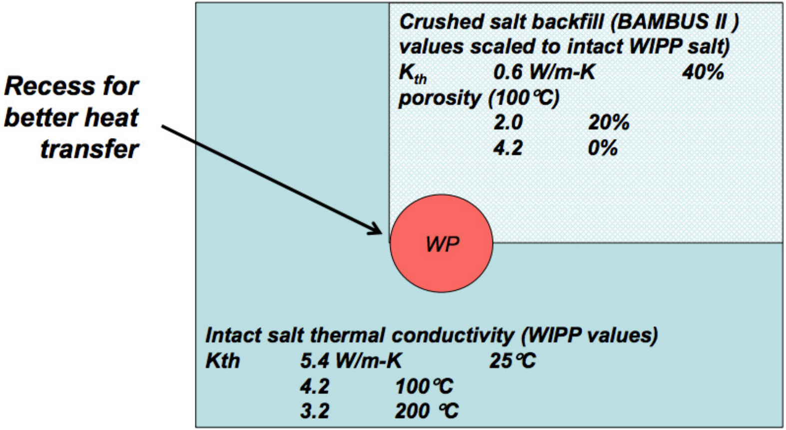


Figure 32: DOE-NE Used Fuel Disposition Campaign concept in Salt [7].

Deep Borehole Disposal Environment

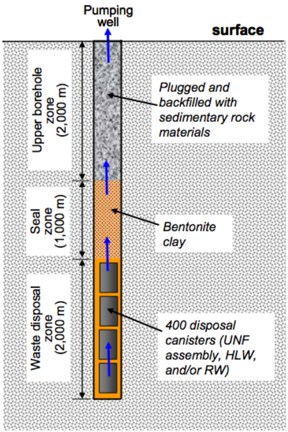


Figure 33: DOE-NE Used Fuel Disposition Campaign Deep Borehole concept [7].

References I

[1] Svensk karnbranslehantering AB.
Long-term Safety for KBS-3 Repositories at Forsmark and Laxemar-a First Evaluation: Main Report of the SR-Can Project.
SKB, November 2006.

[2] Melvin R. Buckner and William E. Burchill.
The case for nuclear fuel recycling.
Nuclear News, 2016.

[3] J. B. Bush.
Economic and Technical Feasibility Study of Compressed Air Storage.
Report ERDA, pages 76–76, 1976.

[4] Daniel Clayton, Geoff Freeze, Ernest Hardin, W. Mark Nutt, Jens Birkholzer, H.H. Liu, and Shaoping Chu.
Generic Disposal System Modeling - Fiscal Year 2011 Progress Report.
Technical Report FCRD-USED-2011-000184, U.S. Department of Energy, Sandia, NM, August 2011.

[5] Peter Essick.
Photographing the Infinity Room - Timing is Everything, April 2012.

References II

[6] Serge Gonzales and Kenneth Sutherland Johnson.
Shales and other argillaceous strata in the United States.
Technical report, Earth Resource Associates, Inc., Athens, GA (USA), 1985.

[7] Ernest Hardin, James Blink, Harris Greenberg, Mark Sutton, Massimo Fratoni, Joe Carter, Mark Dupont, and Rob Howard.
Generic Repository Design Concepts and Thermal Analysis - 8.8.2011 Draft.
Technical Report FCRD-USED-2011-000143, Department of Energy Office of Used Fuel Disposition, Sandia, August 2011.

[8] IAEA.
Country Nuclear Power Profiles.
2015.

[9] NewScientist.
Where should the US store its nuclear waste?
NewScientist, April 2011.

[10] NRC.
Dry cask storage., January 2008.

References III

[11] OMB.
Yucca Mountain 2.jpg, August 2006.

[12] Ichabod Paleogene and Krzysztof Kori.
File:Nuclear power station.svg, 2017.
https://en.wikipedia.org/wiki/File:Nuclear_power_station.svg.

[13] Mark Peters.
What's Next for Used Nuclear Fuel and Nuclear Waste Management Policy?, January 2013.

[14] Christophe Poinssot and Stéphane Gin.
Long-term Behavior Science: The cornerstone approach for reliably assessing the long-term performance of nuclear waste.
Journal of Nuclear Materials, 420(1–3):182–192, January 2012.

[15] Torsch.
Global status of nuclear deployment as of 2017, February 2013.
https://commons.wikimedia.org/wiki/File:Nuclear_Energy_by_Year.svg.

[16] W. von Lensa, R. Nabbi, and M. Rossbach.
RED-IMPACT Impact of Partitioning, Transmutation and Waste Reduction Technologies on the Final Nuclear Waste Disposal.
Forschungszentrum Julich, 2008.