NAMP

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Radiochemistry Webinars

Nuclear Fuel Cycle Series
Nuclear Repository Science

NWP Nuclear Waste Partnership LLC
An AECOM-led partnership with B&W and AREVA

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UNLV

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Virginia Commonwealth University

Meet the Presenter…

Dr. Lindsay Shuller-Nickles

Dr. Lindsay Shuller-Nickles is an Assistant Professor in Environmental Engineering and Earth Science at Clemson University. She teaches undergraduate courses on subjects of mineralogy, petrology, the nuclear fuel cycle, and nuclear waste management and graduate courses on nuclear environmental engineering, technical nuclear forensics, and applications of quantum-mechanical modeling in environmental science. She received her Ph.D. in Materials Science and Engineering from the University of Michigan working with Rod Ewing and Udo Becker. Dr. Shuller-Nickles' research integrates computational and experimental tools to gain a fundamental understanding of the behavior of radionuclide-containing materials in the environment. She currently supports three undergraduate students, four graduate students, and one post-doc working on two funded projects. The first, funded by the Department of Homeland Security, supports her research in nuclear forensics of the characterization of pre- and post-detonation solid materials. The second is an EPSCoR Implementation grant, which funds Dr. Shuller-Nickles' group as part of a much larger project (~$5M for three years). Her work on the EPSCoR grant is focused on quantum-mechanical calculations to understand cation ordering, waste loading, and phase stability for advanced ceramic waste forms. The calculations are performed in collaboration with experimental efforts within the larger EPSCoR group.

Contact Information: lshulle@clemson.edu

CLEMSON UNIVERSITY

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DEPARTMENT OF ENERGY • UNITED STATES OF AMERICA

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

Nuclear Repository Science

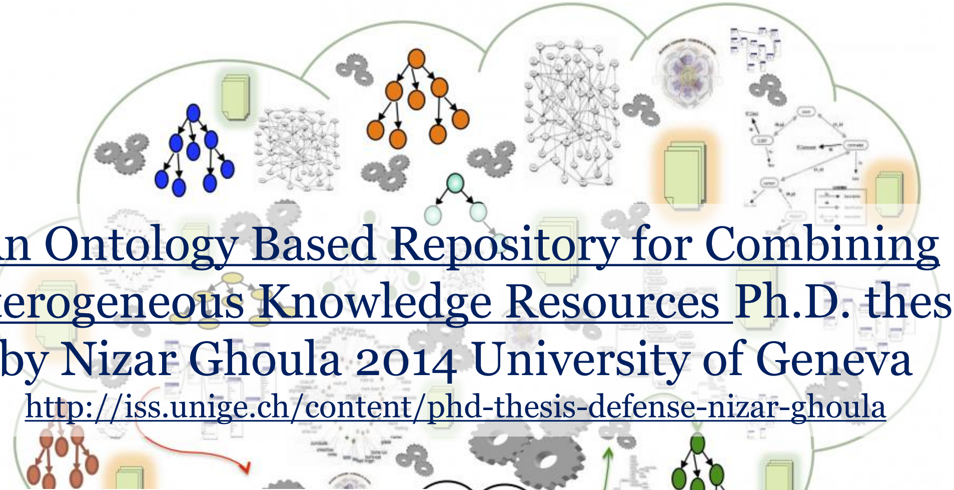
Dr. Lindsay Shuller-Nickles
Clemson University

National Analytical Management Program (NAMP)

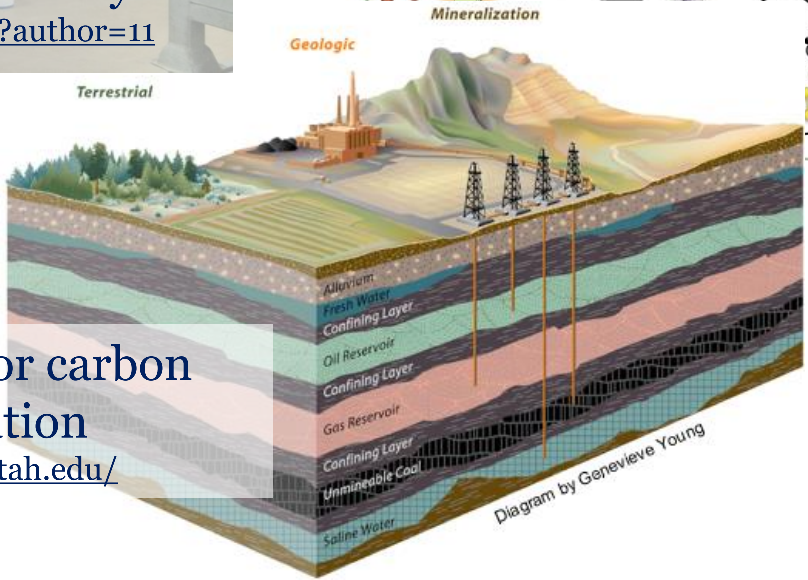
TRAINING AND EDUCATION SUBCOMMITTEE

Repository – a place where a large amount of something is stored

Core-storage room at Bremen Core Repository, Germany
http://science.bennington.edu/?author=11



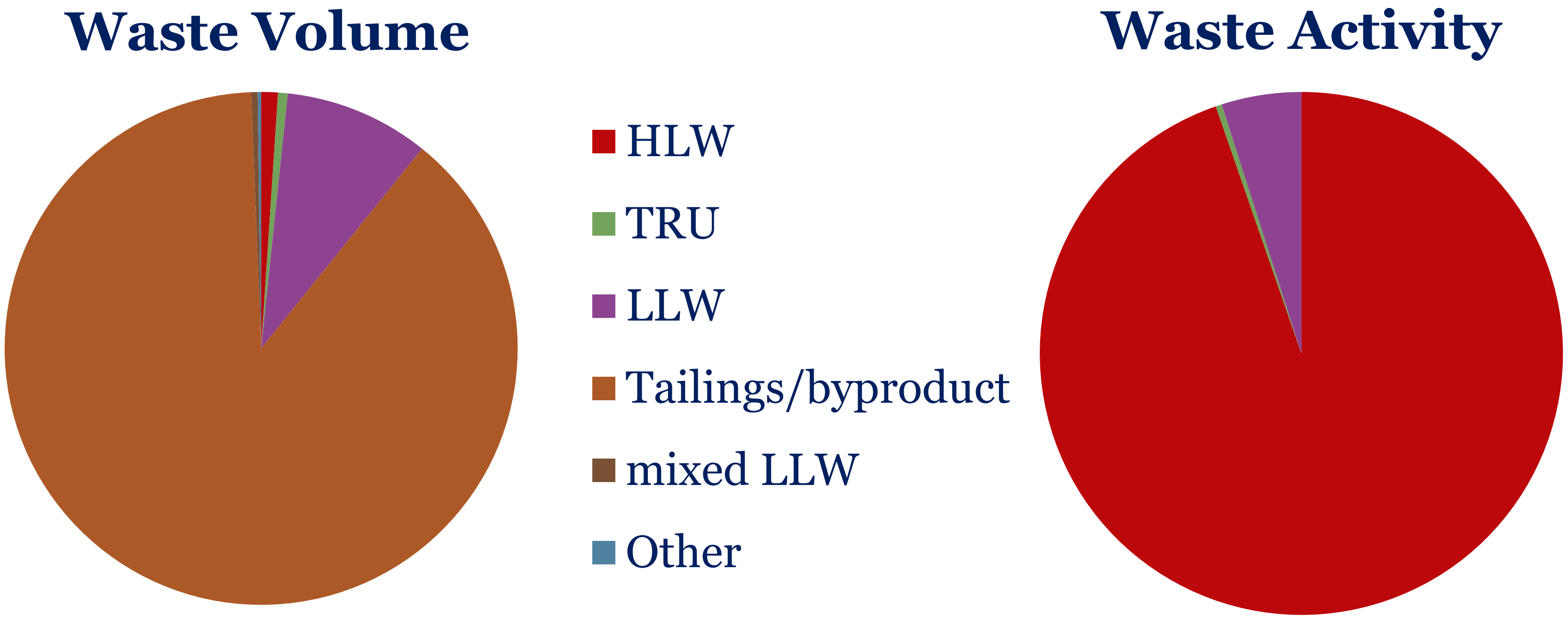
An Ontology Based Repository for Combining Heterogeneous Knowledge Resources Ph.D. thesis by Nizar Ghoula 2014 University of Geneva
http://iss.unige.ch/content/phd-thesis-defense-nizar-ghoula



Repositories for carbon sequestration
http://co2.egi.utah.edu/

Why do we even need to understand nuclear repository science?

- Legacy waste (DOE managed)
  - 36 million m^3 (1010 MCi)



Linking Legacies, DOE-EM 1997

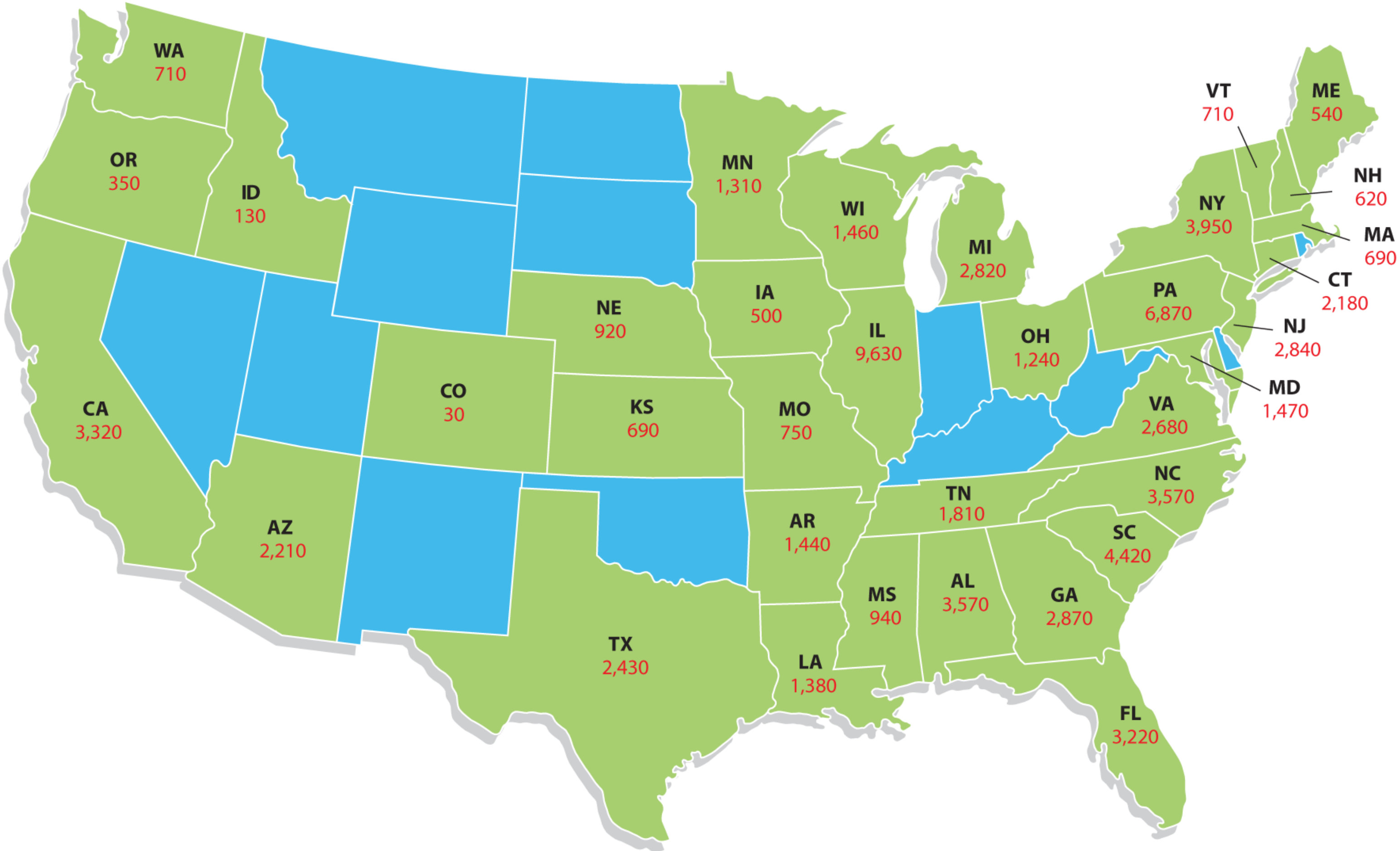
Why do we even need to understand nuclear repository science?

- Legacy waste (DOE managed)
  - 36 million m^3 (1010 MCi)
- Global inventory[1]
  - 300,000 MTHM total
  - 10,000 MTHM annual production
- US civilian inventory[2]
  - ~72,000 MTHM total
  - ~2,200 MTHM annual production

[1] Ewing *Nature Materials* 2015; [2] Government Accountability Office Report GAO-15-141 2014

Used Nuclear Fuel in Storage

(Metric Tons, end of 2014)

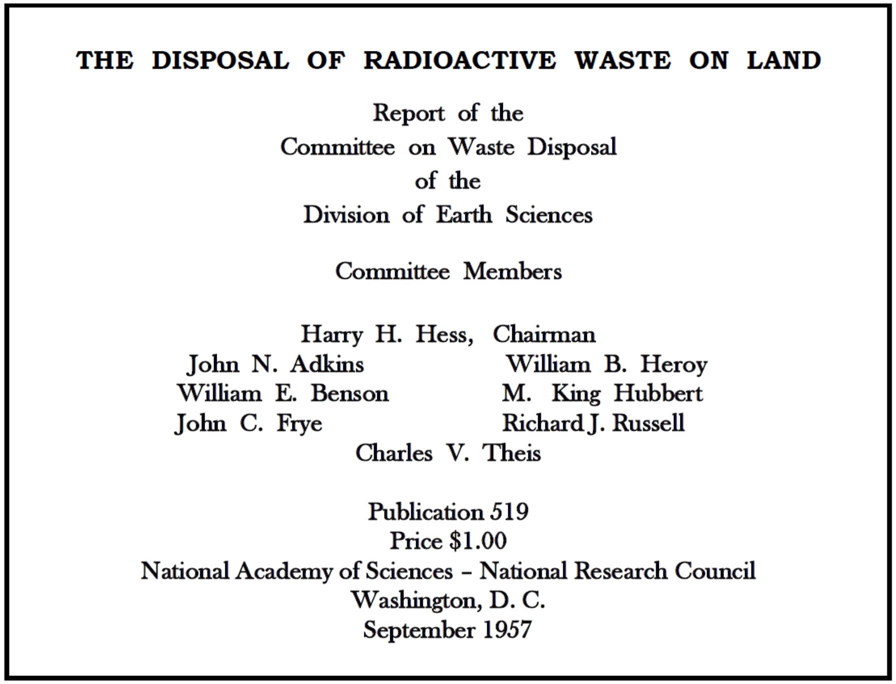


Source: ACI Nuclear Energy Solutions

NUCLEAR ENERGY INSTITUTE

Long term disposal of radioactive waste

- 1957, Academy of Sciences report suggests
  - Underground storage as saf***est*** means for disposal.
  - Salt geology is best.
  - Scientific questions remain unanswered.



THE DISPOSAL OF RADIOACTIVE WASTE ON LAND

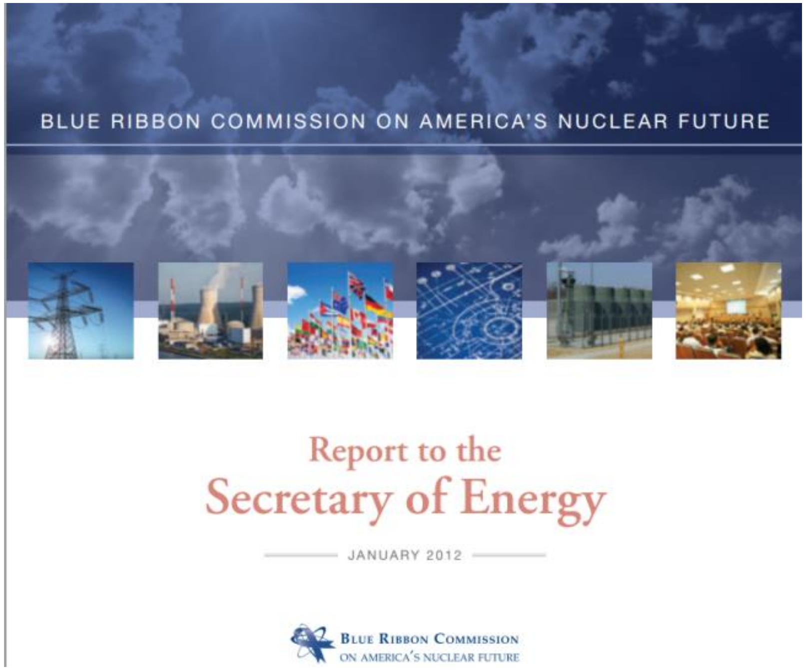
Report of the
Committee on Waste Disposal
of the
Division of Earth Sciences

Committee Members

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

Publication 519
Price $1.00
National Academy of Sciences – National Research Council
Washington, D. C.
September 1957

- 2012, Blue Ribbon Commission's report suggests
  - Underground storage as saf***est*** means for disposal.
  - No specific site recommendations.
  - Scientific questions remain unanswered, but a sense of ***urgency***



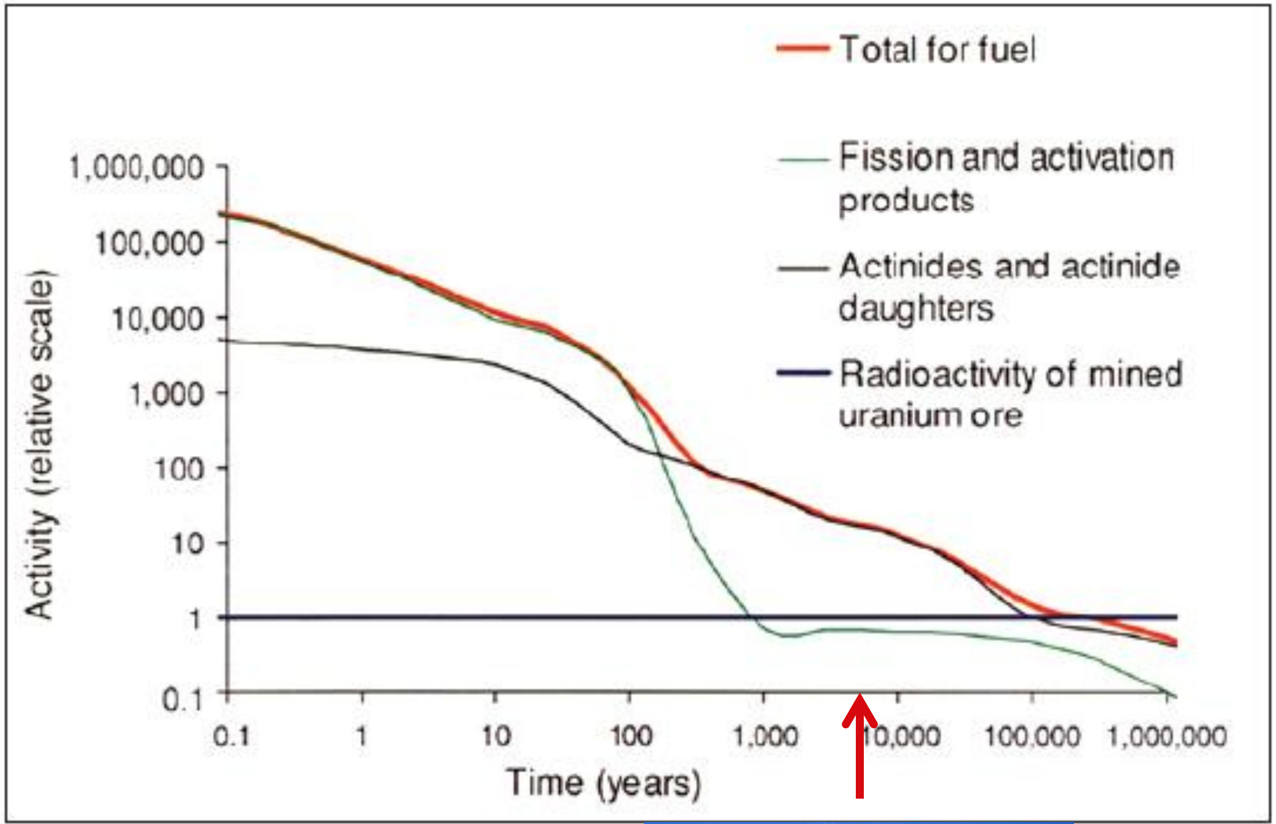
BLUE RIBBON COMMISSION ON AMERICA'S NUCLEAR FUTURE

Report to the
Secretary of Energy

JANUARY 2012

Blue Ribbon Commission
on America's Nuclear Future

Why a geologic repository?



Relative radioactivity of SNF w/ a burn-up of 38 MWd/kg U. The activity is dominated by FP during the first 100 years, thereafter by actinides.

Pyramid of Djoser
27th century BC

Hedin *SKB Report* 1997;
Bruno and Ewing *Elements* 2006

Health and safety requirements for disposal of HLW and SNF

Country	Dose Constraint	Risk Limit	Compliance period
United States	0.15 mSv/yr	Not specified	<10,000 yrs
	1.0 mSv/yr	Not specified	>10,000 yrs, but <1,000,000 yrs
Finland	Less than 0.1 mSv/yr. Release limits for various RNs established.	Not specified.	First several thousand yrs.
	Impacts should be comparable to those arising from natural radioactive materials but should remain insignificantly low.	Not specified.	Beyond first several thousand yrs.
France	0.25 mSv/yr for normal scenarios	Not specified	10,000 yrs
Sweden	Not specified	$<10^{-5}$/yr	100,000 yrs

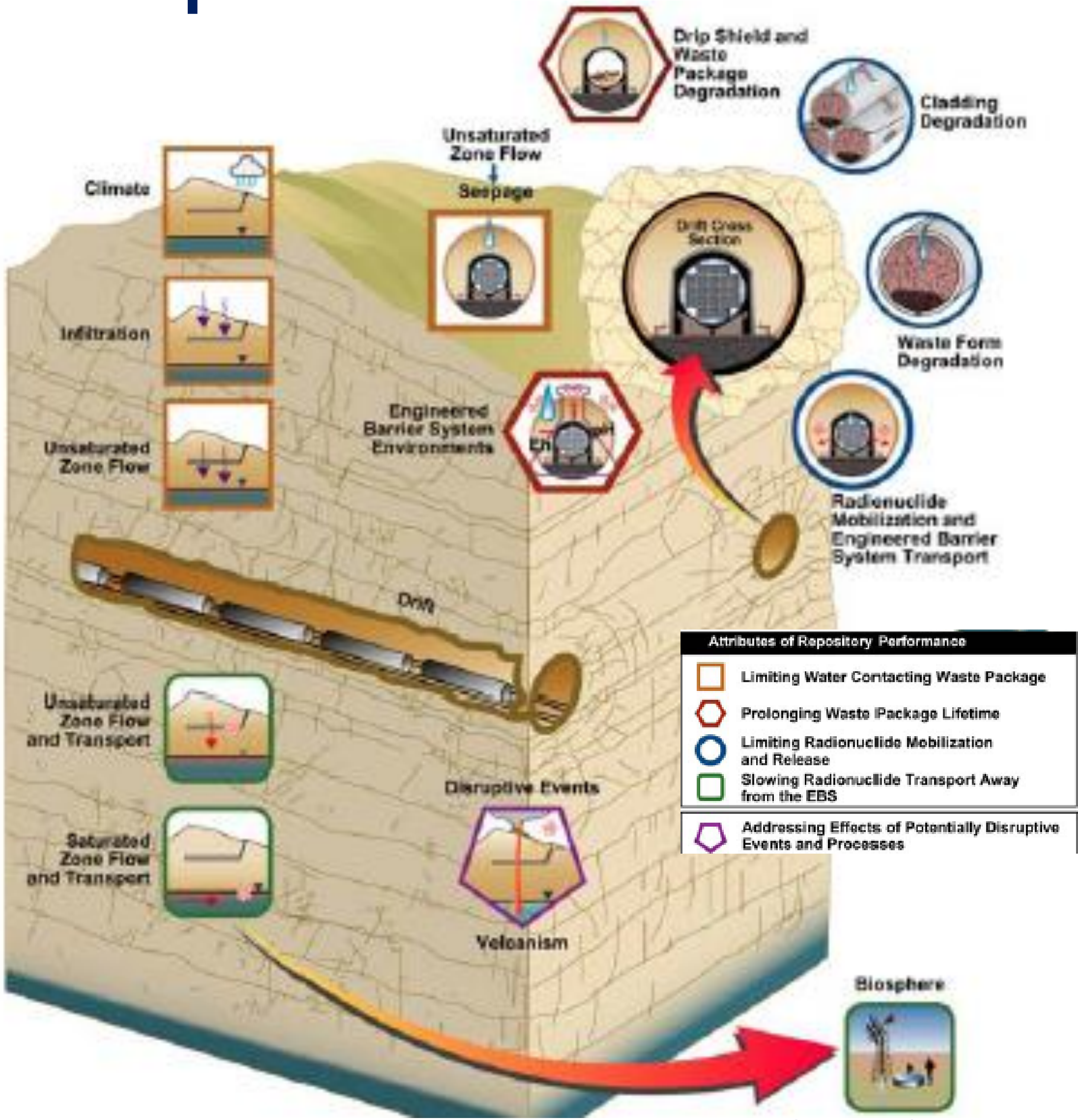
Nuclear Waste Technical Review Board 2009

Demonstrating Compliance w/ Postclosure Standards

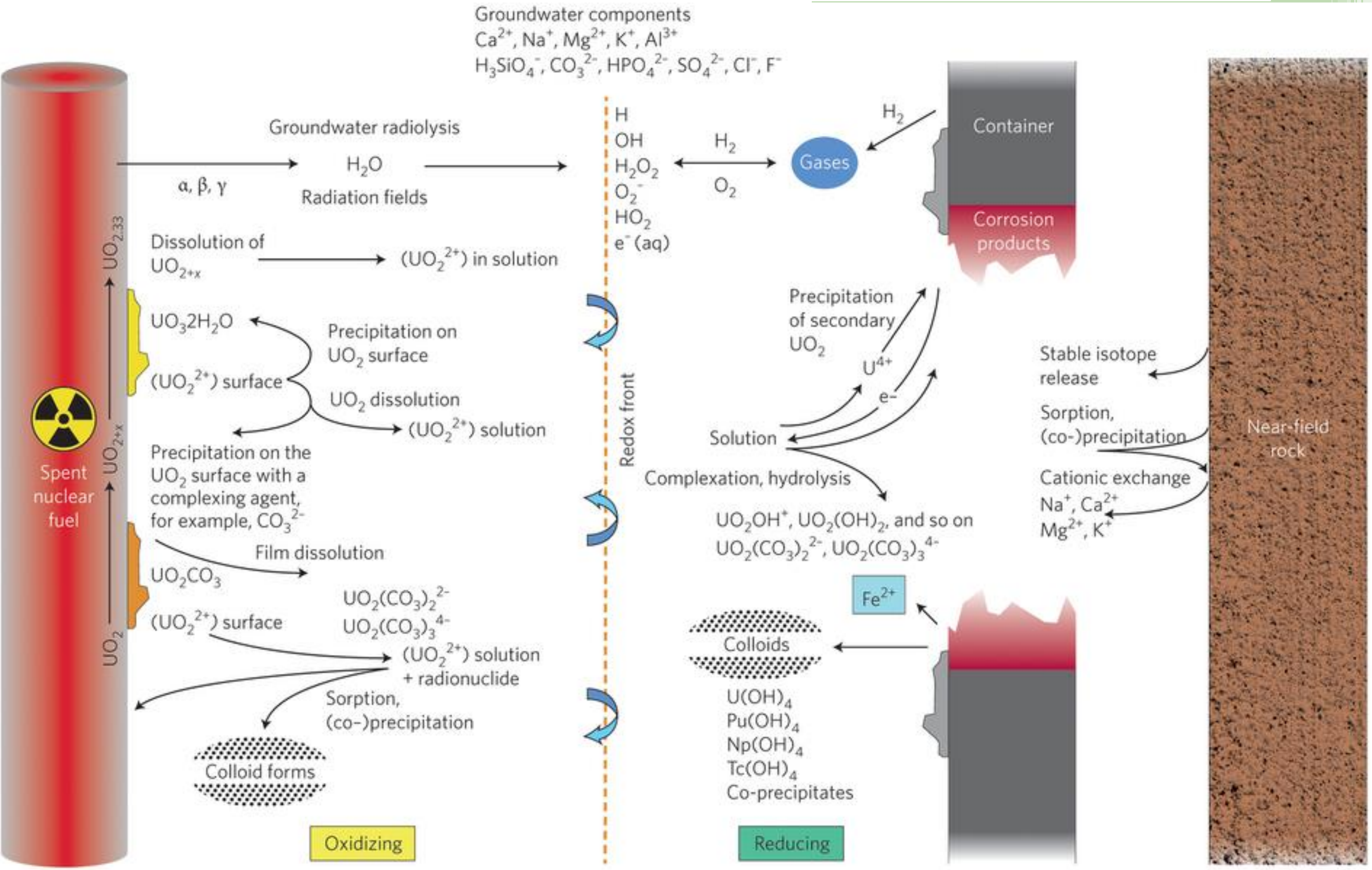
Country	Methodology
United States	Mean value of Monte Carlo realizations generated by a probabilistic Total System Performance Assessment
Finland	Deterministic, conservative safety case that addresses both the expected evolutions and unlikely disruptive events affecting long-term safety. The safety case consists of a numerical analysis based on experimental studies and will be complemented by qualitative expert judgment whenever quantitative analyses are not feasible or are too uncertain
France	Deterministic evaluation of several normal and altered scenarios. In addition, deterministic sensitivity calculations are used to evaluate the impact of uncertainty
Sweden	The regulations do not prescribe a specific methodology for demonstrating compliance. Both deterministic and probabilistic approaches can be used. Three types of scenarios are to be evaluated: (1) Main scenario – based on the probable evolution of the external conditions using realistic or pessimistic assumptions (2) Less probably scenarios – prepared for the evaluation of uncertainties. Include variations on the main scenario with alternative sequences of event. (3) Residual scenarios – include sequences of events and conditions that illustrate the significance of individual barriers and barrier functions.

YM TSPA Model Components

- Major model components are related to the attributes of the repository safety strategy
  - Seepage into Emplacement Drifts
  - Performance of Drip Shield
  - Performance of Waste Package Barriers
  - Solubility Limits of Dissolved Radionuclides
  - Retardation of Radionuclide Migration in UZ, SZ, and combinations thereof
- Natural and engineered barriers comprise the total system

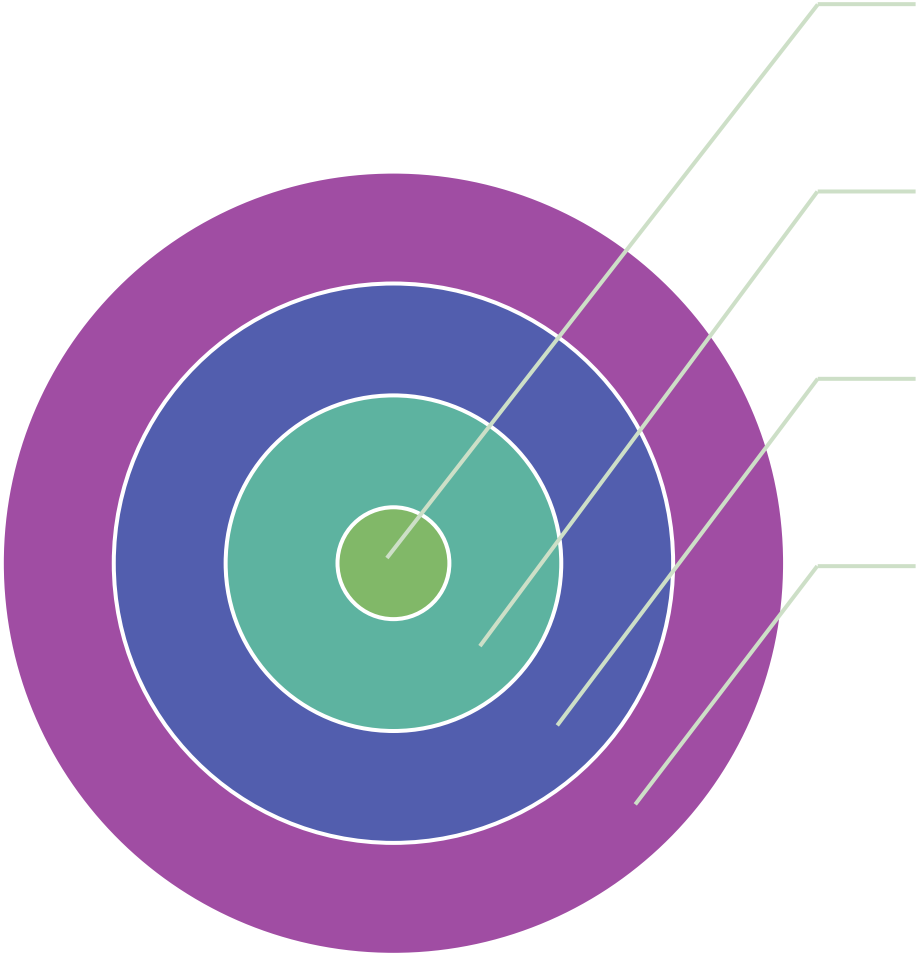


CRWMS 2000



Ewing *Nature Materials* 2015

Multi-Barrier Approach



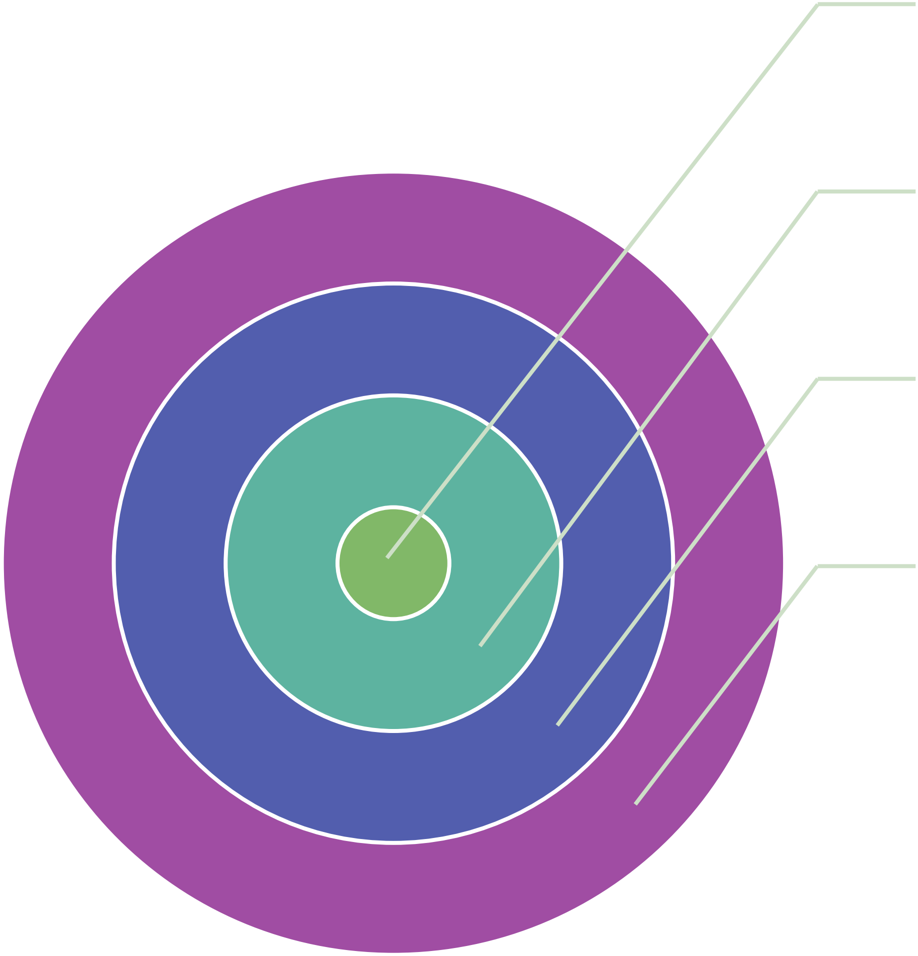
Waste Form

Canister

Overpack/Buffer/ Backfill

Repository

Multi-Barrier Approach



Waste Form

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What is a Waste Form?

- Chemical form of the material holding the nuclear waste.

- Ideal waste form depends on the type of material being disposed.
  - Specific activity, half-life, chemical speciation

- Long term disposal --> long lived isotopes
  - If not reprocessing prior to disposal, some moderate half-life isotopes (*e.g.*, Cs-137, $t_{1/2} = 30.9$ yr) remain in waste.

Examples of Waste Forms

- Spent nuclear fuel
- Borosilicate glass
- Ceramics (polycrystalline)
  - Synroc
  - Tailored ceramics
  - Glass-ceramics
  - Fuetap
- Ceramics (single phase)
  - titanate
  - zircon
  - pyrochlore
- "Novel" types
  - High silica porous glass matrix
  - Low-temperature hydroxylated ceramics
  - Clay & zeolite assemblages

- Multi-barrier
  - Coated particles (e.g., TRISO fuels)
  - Vitromet
  - Cermet

Principal Considerations for Waste Forms

- Chemical complexity of waste
- Large volumes of waste
- Ease of processing (and radiation safety)
- Durability (long-term) of waste form

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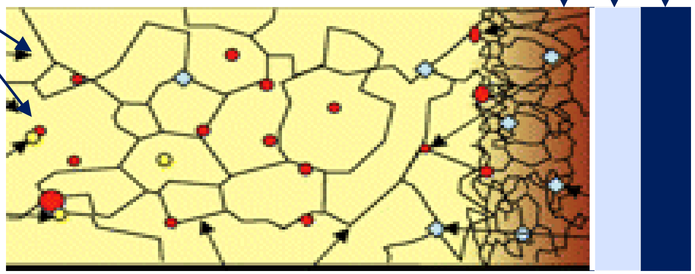
What is the chemical make-up of the waste?



Cladding: C

Gap Region: C, I, S, Cs, Se, Tc

Rim Enriched in Pu

Fuel Grains:
$(U, An, Ln)O_2$

Fission Gas Bubbles:
Xe, Kr, I

Grain Boundaries:
C, I, S, Cs, Se, Tc

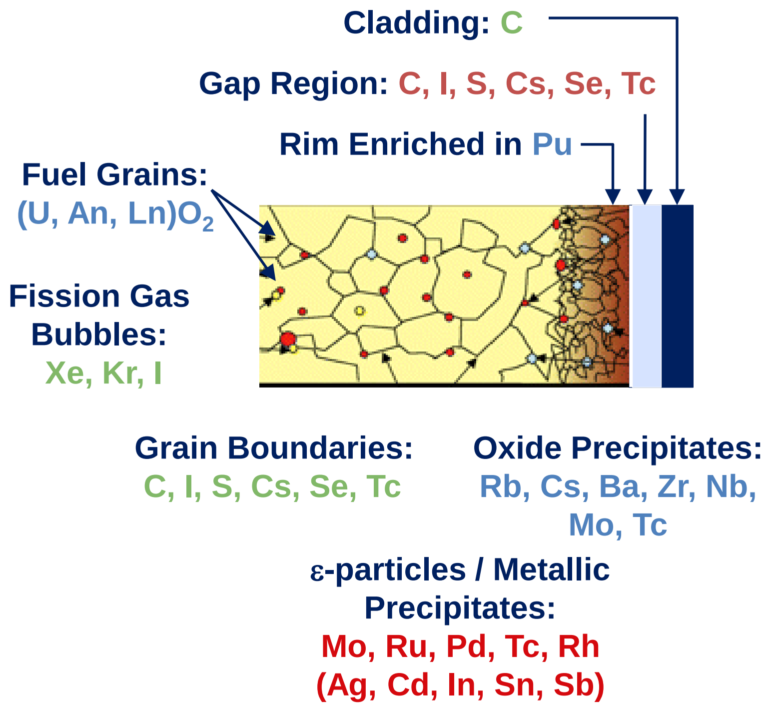
Oxide Precipitates:
Rb, Cs, Ba, Zr, Nb, Mo, Tc

ε-particles / Metallic Precipitates:
Mo, Ru, Pd, Tc, Rh
(Ag, Cd, In, Sn, Sb)

Modified from Bruno and Ewing *Elements* 2006

What is the chemical make-up of the waste?

Disposal Scheme	**Direct Disposal**	**Reprocessing**
Used fuel treatment	Cooling in wet and dry storage	Cooling followed by reprocessing
Waste form for disposal	Used nuclear fuel (oxide)	Engineered waste form (e.g., glass)



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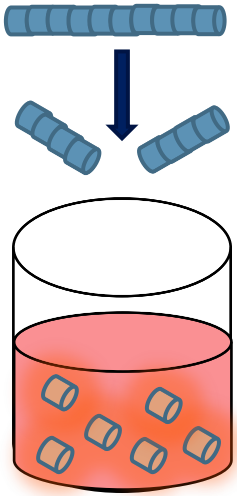
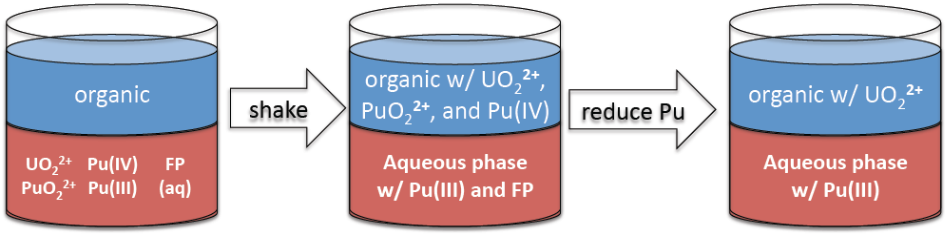




Aside: If we consider reprocessing, is this discussion of a geologic repository even necessary???

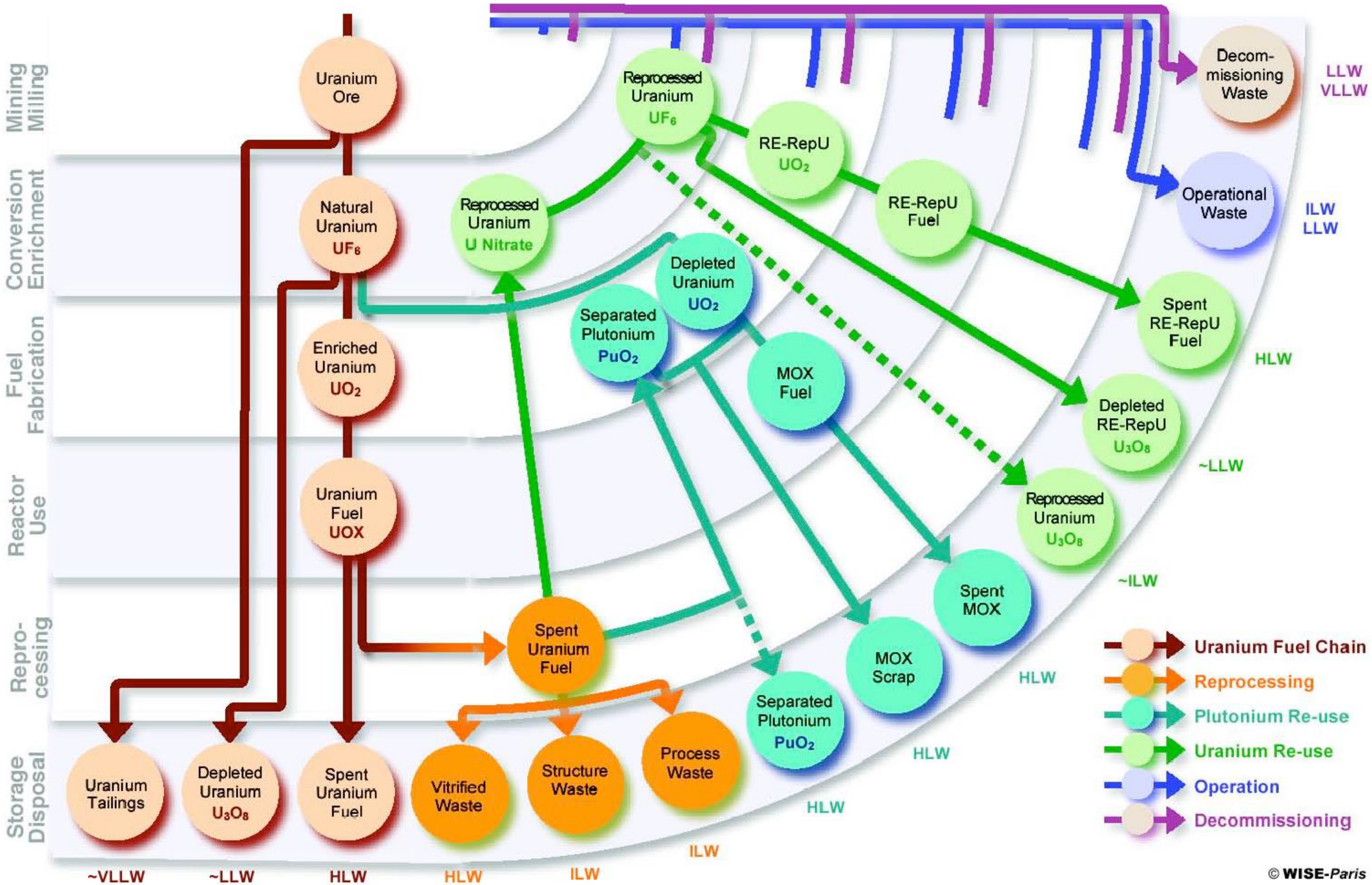
- Current Inventory: 72,000 MTHM

- US annual production: 2000 MTHM SNF
- La Hague annual capacity: 1700 tonnes per year[1]

- More complex waste stream[2]

[1] www.world-nuclear.org; [2] International Panel on Fissile Materials (2008)

Aside: If we consider reprocessing, is this discussion of a geologic repository even necessary???



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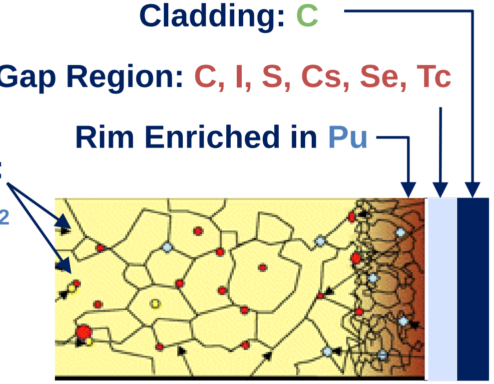

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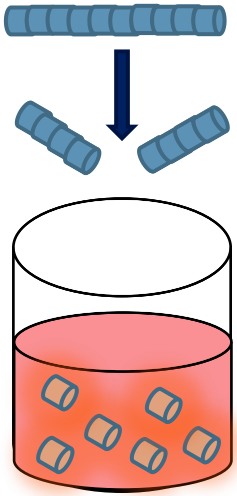

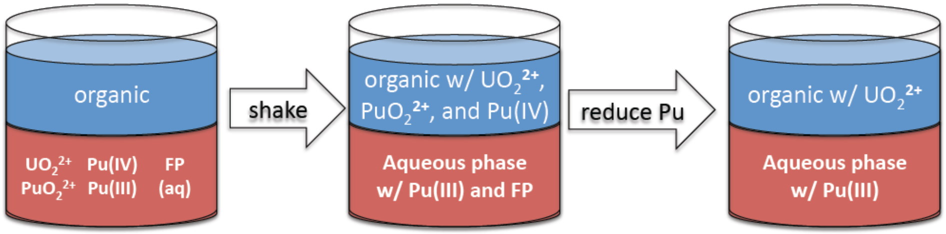

Chemical Complexity - Fission Products

- Multi-phase waste forms
  - Take advantage of complex waste stream
    - e.g., Where does the Mo go?
      - Glass – soluble Cs-Mo-phase → release of Cs
      - Ceramic – may incorporate into hollandite

        $(Ba_xCs_y)(A^{+3})_{2x+y}(Ti^{+4})_{8-2x-y}O_{16}$
      - Metallic – alloys

    - Therefore…a multi-phase waste form (e.g., glass-ceramic) could help solve the Mo problem for glass waste forms.

Principal Considerations for Waste Forms

- Chemical complexity of waste
- **Large volumes of waste**
- Ease of processing (and radiation safety)
- Durability (long-term) of waste form

Waste loading

Waste form	Main phases	Application (waste loading)
Spent nuclear fuel	uraninite (~96%)	SNF from civilian NPP (100%)
Synroc-C	zirconolite, perovskite, hollandite, rutile	HLW from reprocessing (20%)
Synroc-D	zirconolite, perovskite, spinel, nepheline	US defense wastes (60-70%)
Pyrochlore	pyrochlore, zirconolite-4M, brannerite, rutile	Separated actinides (35 wt%)
Monazite	monazite	Actinide-lanthinide wastes (25 wt%)
Borosilicate glass	glass, minor ceramics or soluble CsMo phase	Up to 20-30 wt%

Depends on chemical complexity, chemical compatibility, resistance to radiation damage

Grambow *Elements* 2006; Lumpkin *Elements* 2006

Principal Considerations for Waste Forms

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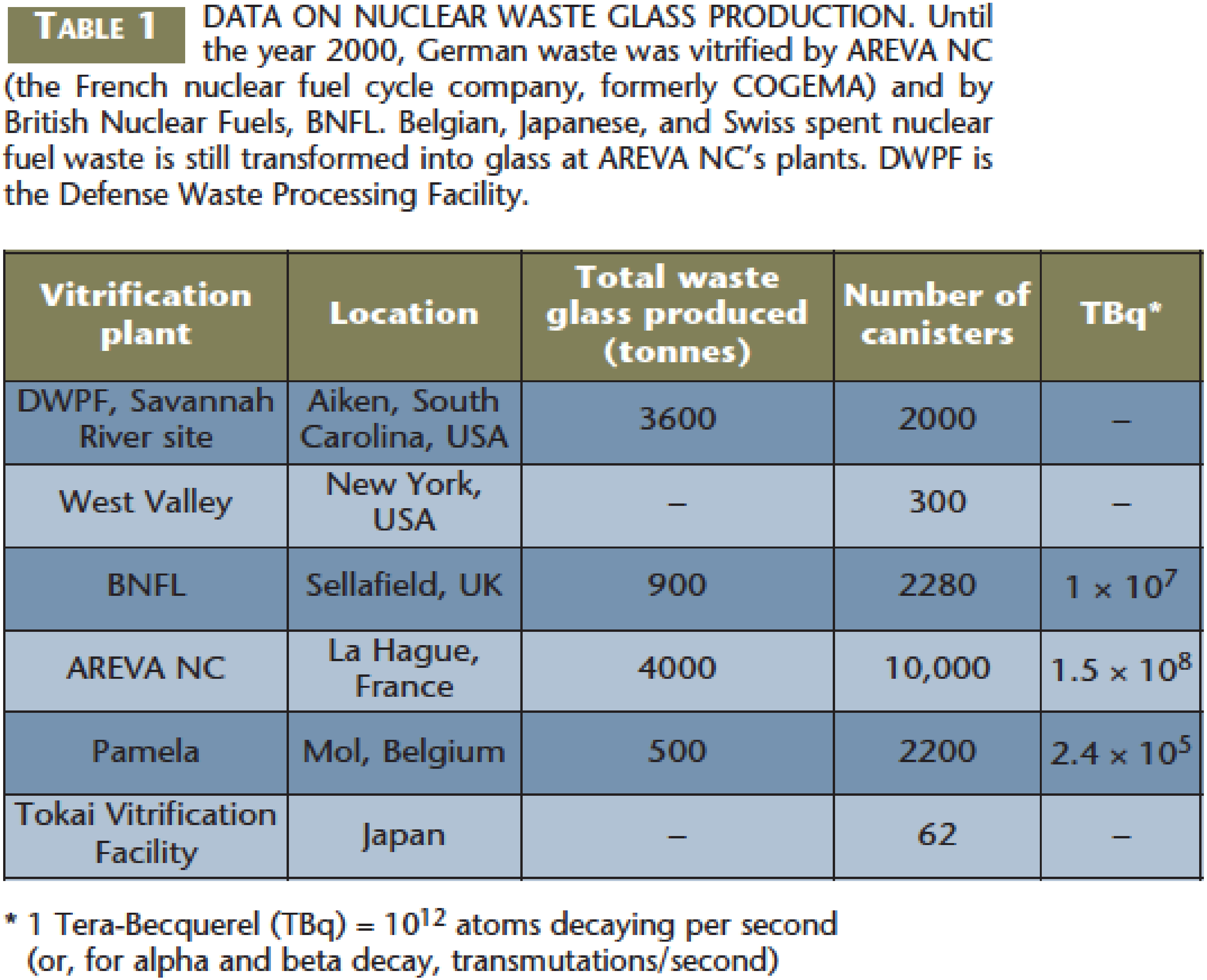


TABLE 1 DATA ON NUCLEAR WASTE GLASS PRODUCTION. Until the year 2000, German waste was vitrified by AREVA NC (the French nuclear fuel cycle company, formerly COGEMA) and by British Nuclear Fuels, BNFL. Belgian, Japanese, and Swiss spent nuclear fuel waste is still transformed into glass at AREVA NC's plants. DWPF is the Defense Waste Processing Facility.

Vitrification plant	Location	Total waste glass produced (tonnes)	Number of canisters	TBq*
DWPF, Savannah River site	Aiken, South Carolina, USA	3600	2000	–
West Valley	New York, USA	–	300	–
BNFL	Sellafield, UK	900	2280	1×10^7
AREVA NC	La Hague, France	4000	10,000	1.5×10^8
Pamela	Mol, Belgium	500	2200	2.4×10^5
Tokai Vitrification Facility	Japan	–	62	–

* 1 Tera-Becquerel (TBq) = 10^{12} atoms decaying per second (or, for alpha and beta decay, transmutations/second)

Grambow *Elements* 2006

Ease of Processing Demonstrated at the Defense Waste Processing Facility

- Projections (1981)
  - $800 million
  - 1990 start-up
  - "…well established technology…"

- Actual
  - $4 billion
  - 1996 start-up
  - "…first-of-a-kind technology that was well ahead of its time."

Wicks et al. 1993 Materials Research Society Bulletin

- "… the ***excellent stability and technical performance*** of waste glass forms and the ability of the glass… to retain radionuclides even when exposed to potential leachants within a repository environment."
- "These advantages fall into two general areas:
  - (a) … good versatility, chemical durability, mechanical integrity, and radiation and thermal stability, and
  - (b) ease of fabrication … well developed and demonstrated."

Modified from slides from Rod Ewing

Principal Considerations for Waste Forms

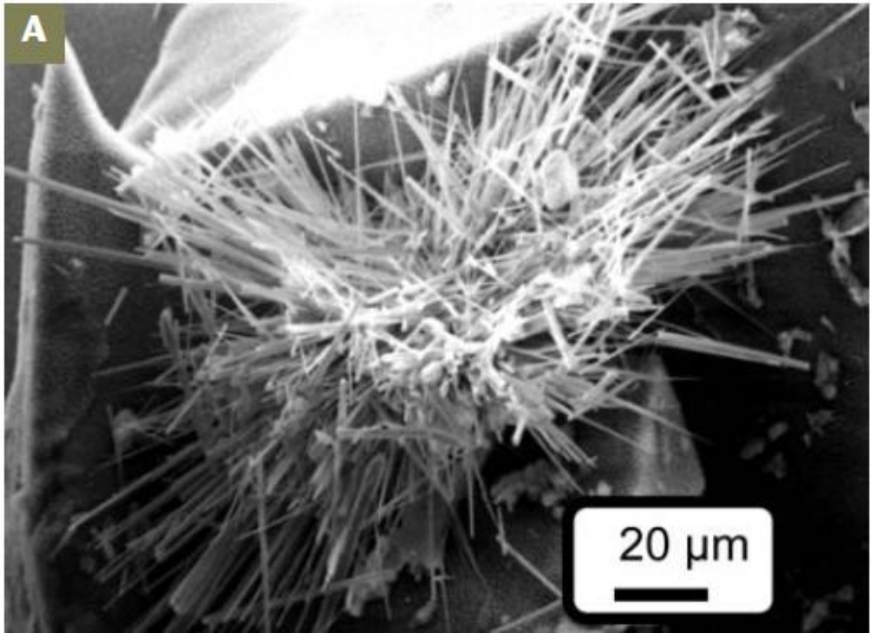
- Chemical complexity of waste
- Large volumes of waste
- Ease of processing (and radiation safety)
- **Durability (long-term) of waste form**

Grambow (1994)
Materials Research Society Bulletin

- "However, the glass corrodes slowly in water and humid air, and inevitably, certain quantities of radionuclides are mobilized. The glass is ***not inherently corrosion-resistant***, but rather depends on the waste package and on surrounding geochemical and hydrological constraints."

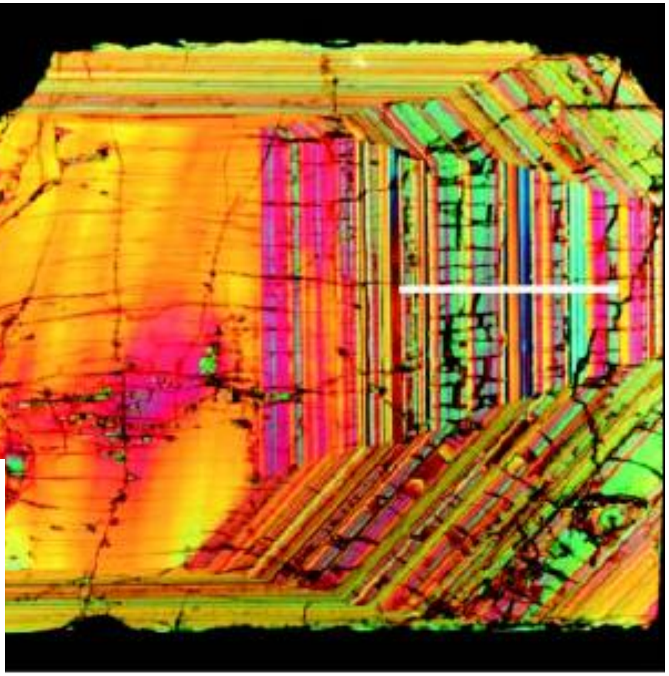
Uranyl silicate mineral formed during leaching of AREVA NC-type glass in NaCl-rich brines

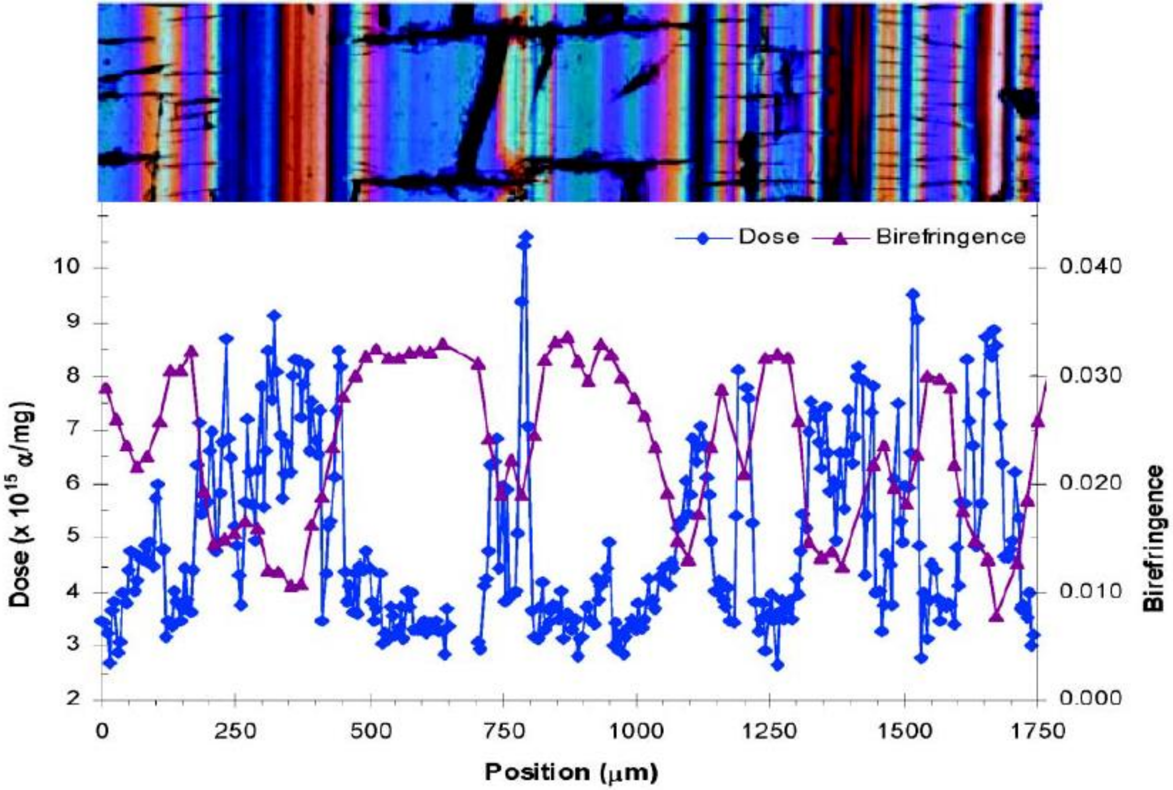
- Experiments performed at the Hahn Meitner Institute, Berlin at 110 °C, S/V = 2100 m^{-1} for 831 days.



Grambow *Elements* 2006

Zircon from Sri Lanka (560 Ma)

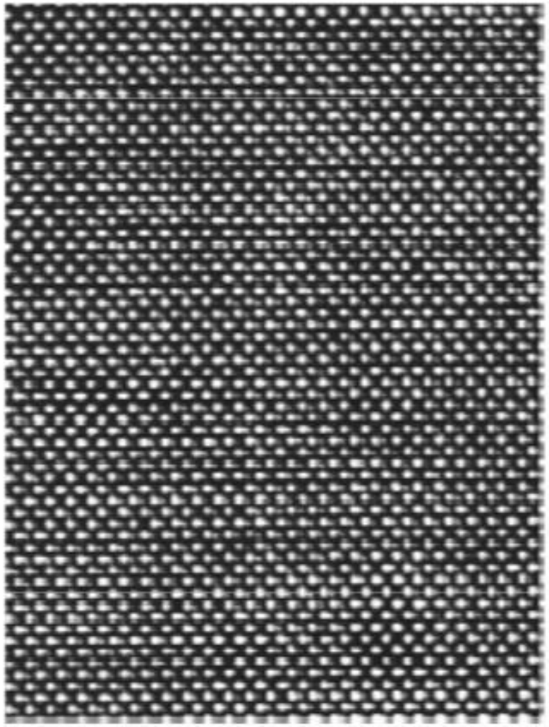




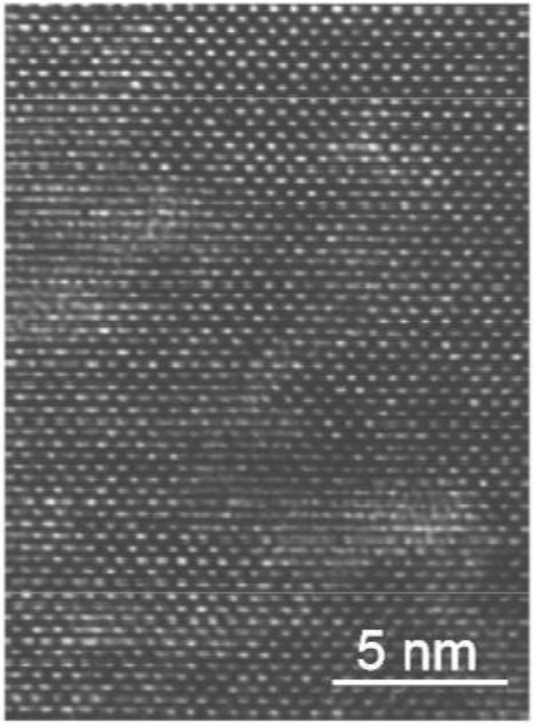
The inverse relationship between dose and birefringence as a function of position

Palenik et al. *Am. Min.* 2003

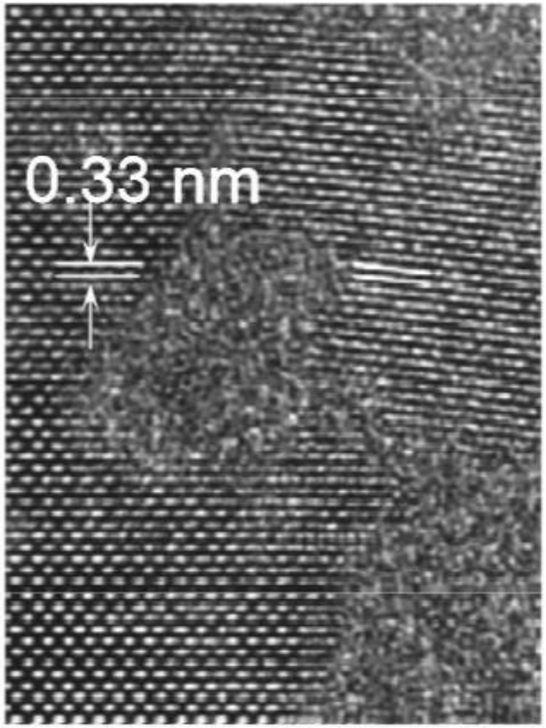
Radiation Damage in Natural Zircon from Alpha Decay and Ion Irradiation



Undamaged
(no U or Th)



Alpha-Decay Damaged
Over 550 Million Years
From U & Th Decay

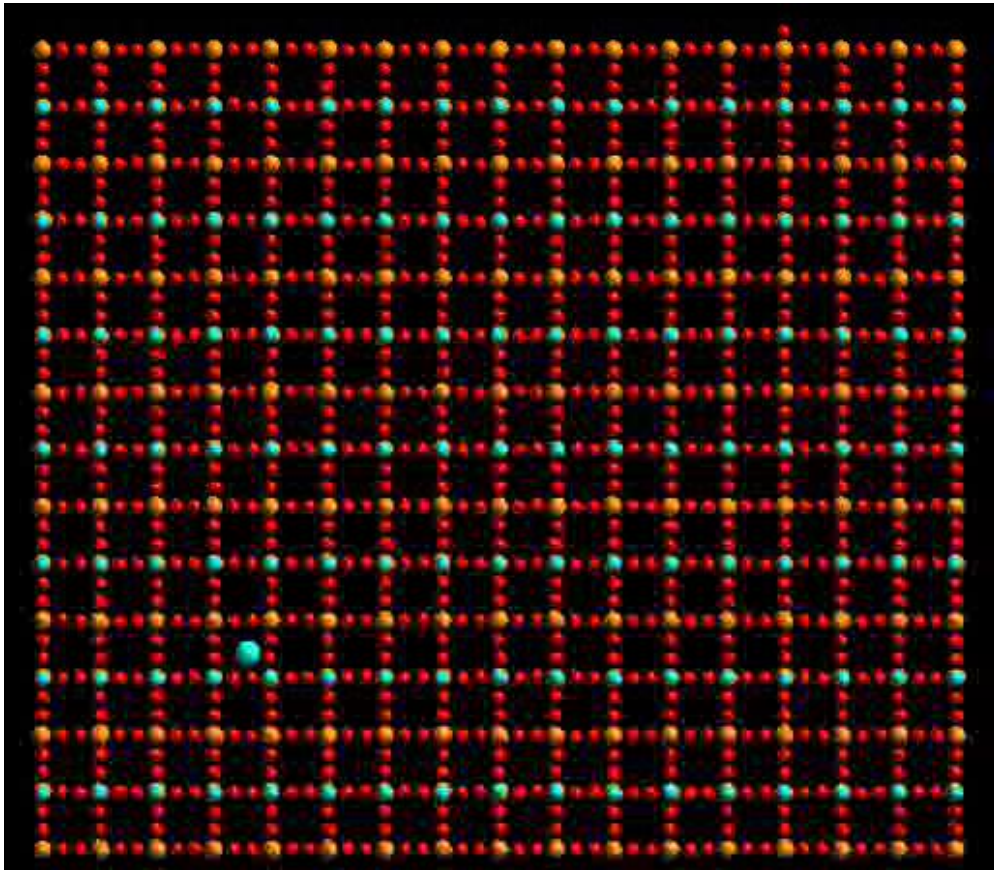


Ion Irradiation Damage
1.5 MeV Kr^+ Ions

Modified from Weber EFRC Summer School 2012 slides; Weber et al. *J. Mater. Res.* 1994

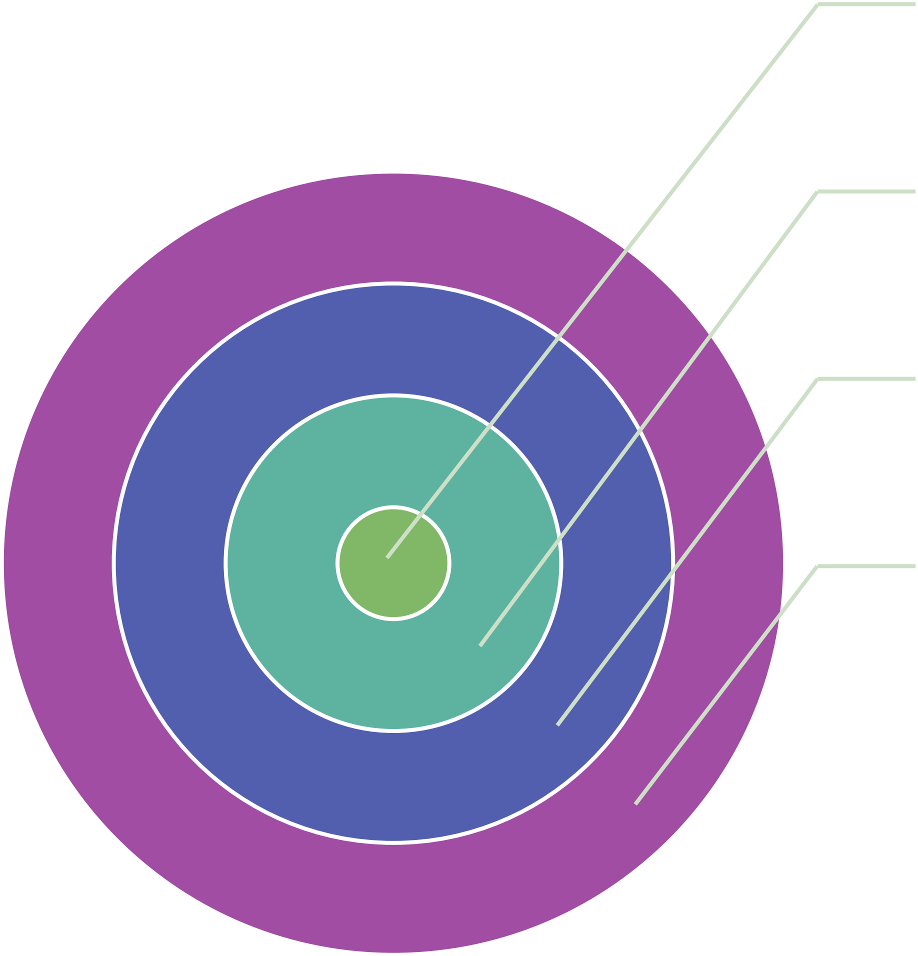
Molecular Dynamics Simulation of Atomic Collision Cascade:

30 keV U recoil in zircon



Kostya Trachenko (Queen Mary College, UK)

Multi-Barrier Approach



Waste Form

Canister

Overpack/Buffer/
Backfill

Repository

Canister functionality

https://www.youtube.com/watch?v=1eJMY9MT4a8&feature=youtu.be&t=11

Candidate Canister Materials

Country	Proposed Canister material		Relevant alteration phases
	outer canister	inner canister	
United States	Alloy-22	Stainless steel	magnetite, maghemite, hematite, akaganeite, lepidocrocite, goethite, siderite, green rust
Belgium	Carbon steel *	Stainless steel	
Japan	Carbon steel	Stainless steel	
Switzerland	Cast iron	Stainless steel	
Finland	Copper	Cast-iron	reddish brown cuprous oxide, Cu_2O; green copper carbonates, sulfates, or oxychlorides; black copper sulfides
Sweden	Copper	Cast-iron	

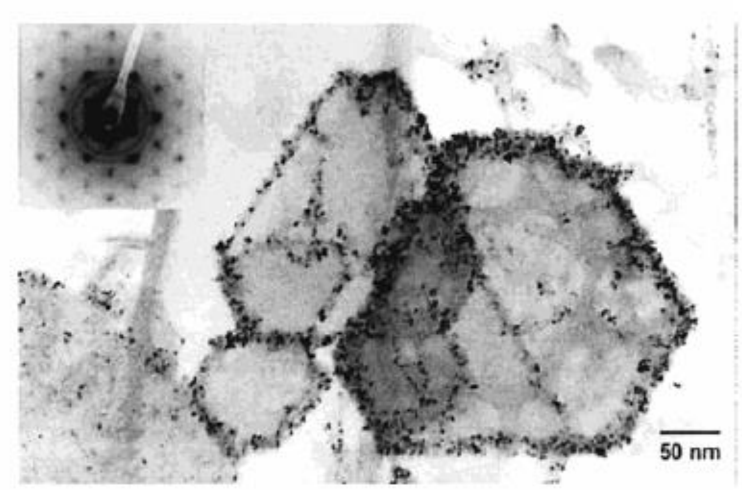
* surrounded by thick concrete

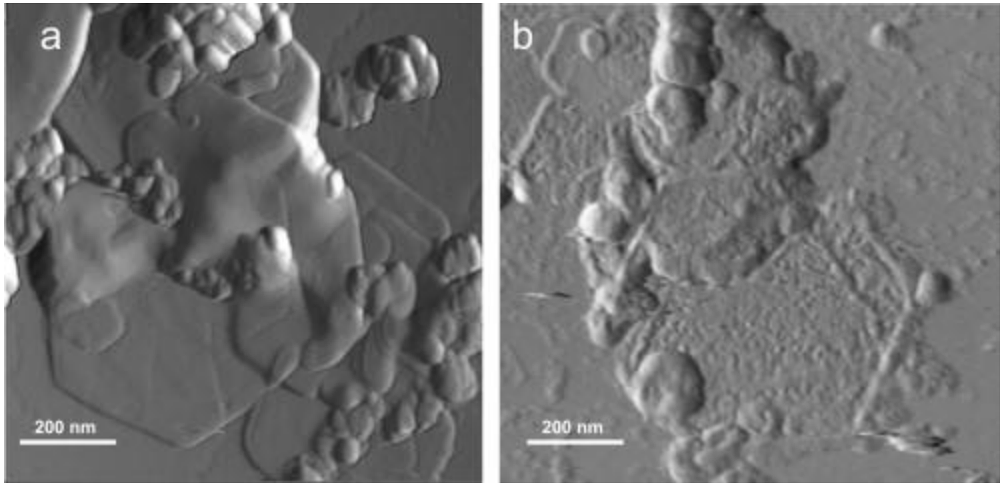
Nuclear Waste Technical Review Board 2009

Fe-container as a Chemical Barrier: Formation of Green Rust $[Fe(II)_4Fe(III)_2(OH)_{12}][CO_3/SO_4/OH \cdot X\ H_2O]$

- TEM image of U(VI) reaction with GR-OH

- AFM showing Np reacted GR-Na,SO_4





O'Loughlin et al. ES&T 37 (2003) 721.

Christiansen et al. GCA 75 (2011) 1216.

Fe-container as a Chemical Barrier

Journal of Nuclear Materials 384 (2009) 130–139

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journal homepage: www.elsevier.com/locate/jnucmat

UO_2 corrosion in an iron waste package

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[b] *Sandia National Laboratories, P.O. Box 5800, MS 0779, Albuquerque, NM 87185-0779, USA*

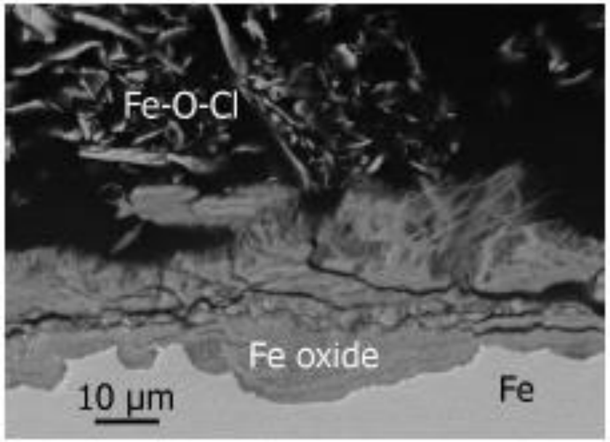


Figure 2.6. Back-scattered electron micrographs of Package D corroded steel of at 90 days. The polished cross-section shows oxidized areas along the steel surface and loosely consolidated fibers or plates of a Cl-rich phase.

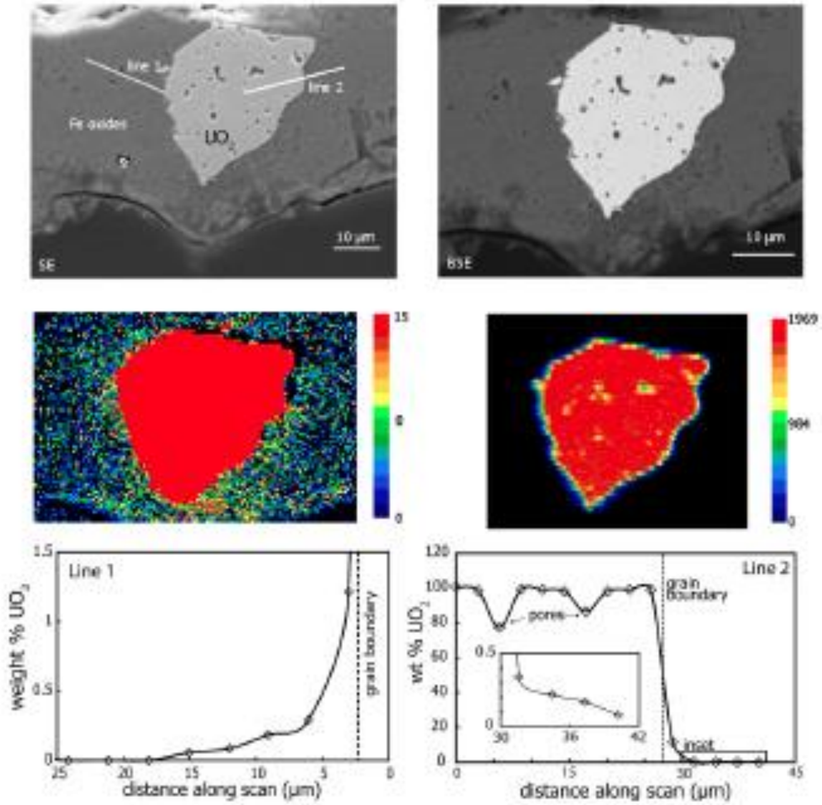
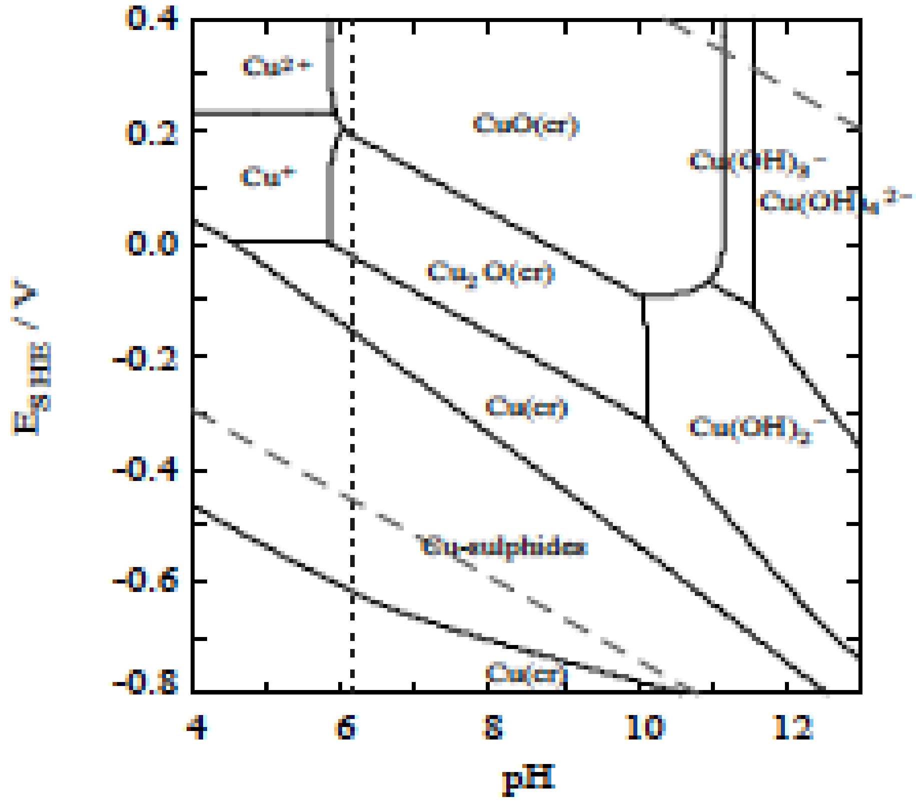


Figure 2.9. Secondary electron (SE) and back-scattered electron (BSE) image of UO_2 grain surrounded by steel corrosion products (most likely magnetite) in package E with associated EMPA/WDS line scans and elemental maps of U focused at different levels of total counts per pixel.

Cu-Container as a Chemical Barrier

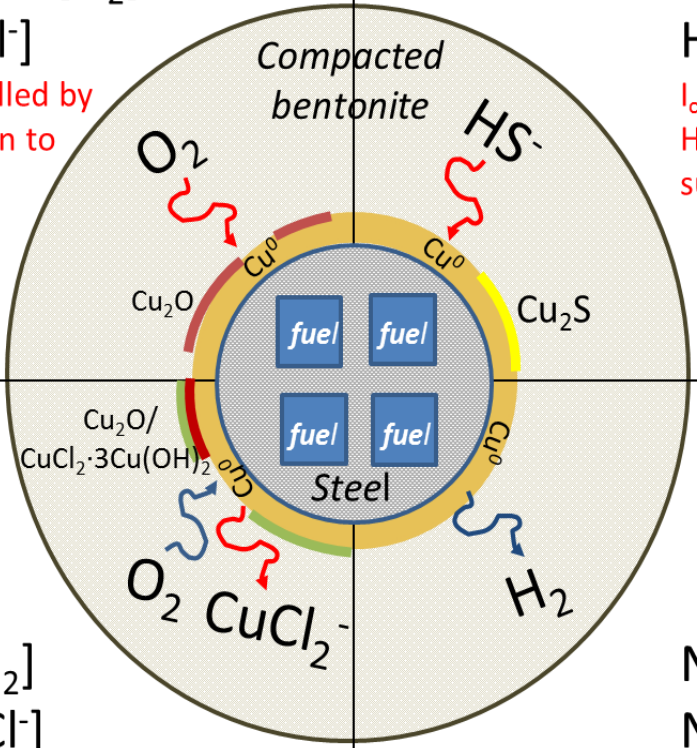
Estimated Lifetime > 100,000 years



Pourbaix diagram for copper in solutions containing $[HS^-]_{TOT} = 0.2$ mmol/kg & $[Cu]_{TOT} = 10^{-6}$ mol/kg @ 100 °C

Puigdomenech et al. “Thermodynamic data for copper: Implications for the corrosion of copper under repository conditions” SKB 2000.

Cu case study(s)



High-low $[O_2]$
Low $[Cl^-]$
I_{corr} controlled by O_2 diffusion to surface

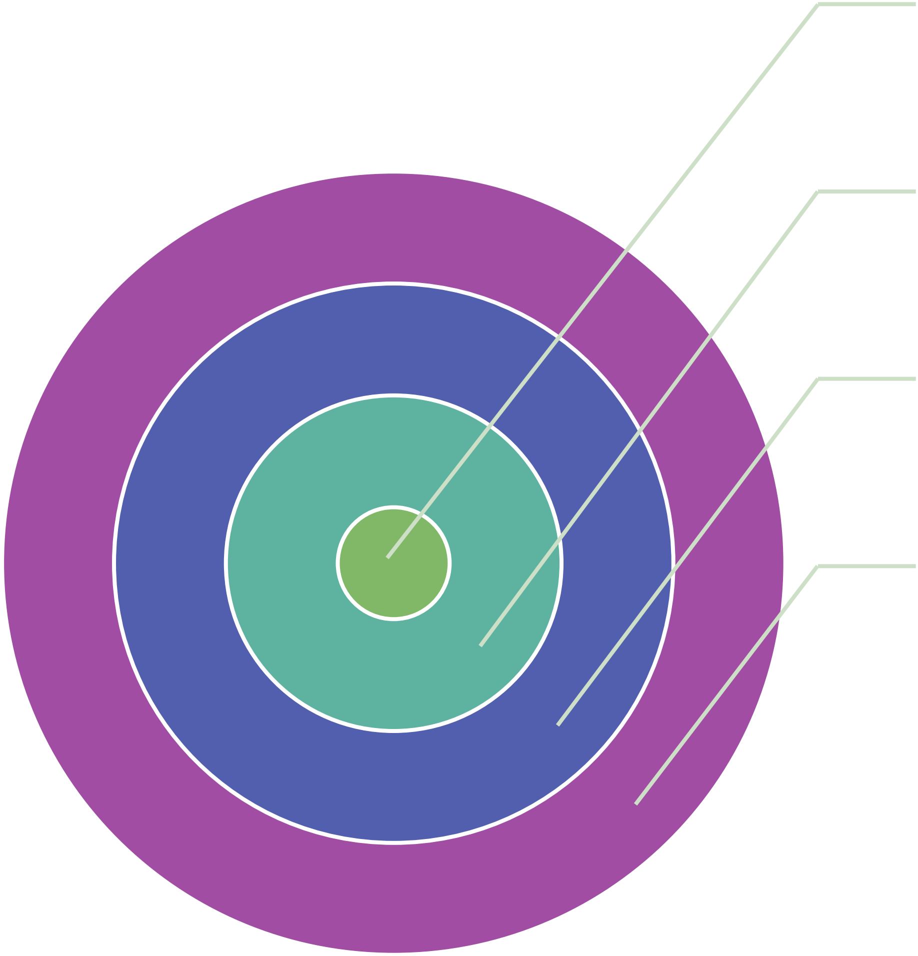
No $[O_2]$
High-low $[HS^-]$
I_{corr} controlled by HS^- diffusion to surface

Low $[O_2]$
High $[Cl^-]$
I_{corr} controlled by $CuCl_2^-$ diffusion away from surface

No $[O_2]$
No $[HS^-]$
I_{corr} controlled by ???
Further studies required.

Renock and Shuller-Nickles
Elements (2015) in press.

Multi-Barrier Approach



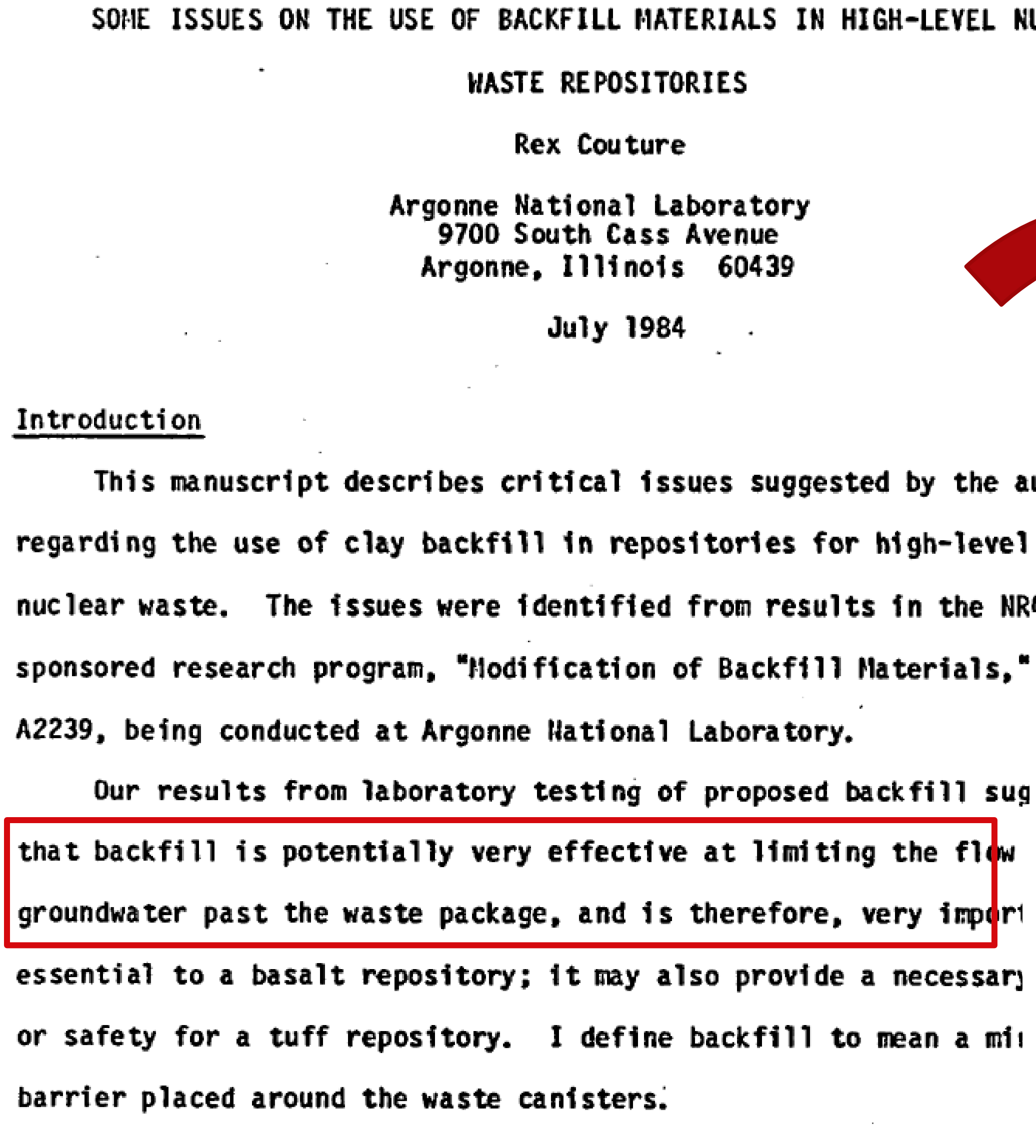
Waste Form

Canister

Overpack/Buffer/ Backfill

Repository

Clay backfill



SOME ISSUES ON THE USE OF BACKFILL MATERIALS IN HIGH-LEVEL NUCLEAR

WASTE REPOSITORIES

Rex Couture

Argonne National Laboratory
9700 South Cass Avenue
Argonne, Illinois 60439

July 1984

Introduction

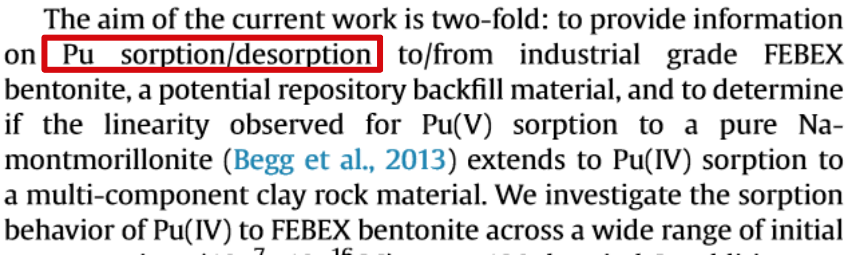
This manuscript describes critical issues suggested by the author regarding the use of clay backfill in repositories for high-level nuclear waste. The issues were identified from results in the NRC-sponsored research program, "Modification of Backfill Materials," A2239, being conducted at Argonne National Laboratory.

Our results from laboratory testing of proposed backfill sug that backfill is potentially very effective at limiting the flow groundwater past the waste package, and is therefore, very import essential to a basalt repository; it may also provide a necessar or safety for a tuff repository. I define backfill to mean a mi barrier placed around the waste canisters.

http://pbadupws.nrc.gov/docs/ML0320/ML032060230.pdf

30 years later…there's still more to learn about backfill materials

Begg J.D. et al. *J. of Env. Radioact. 141 (2015) 106.*

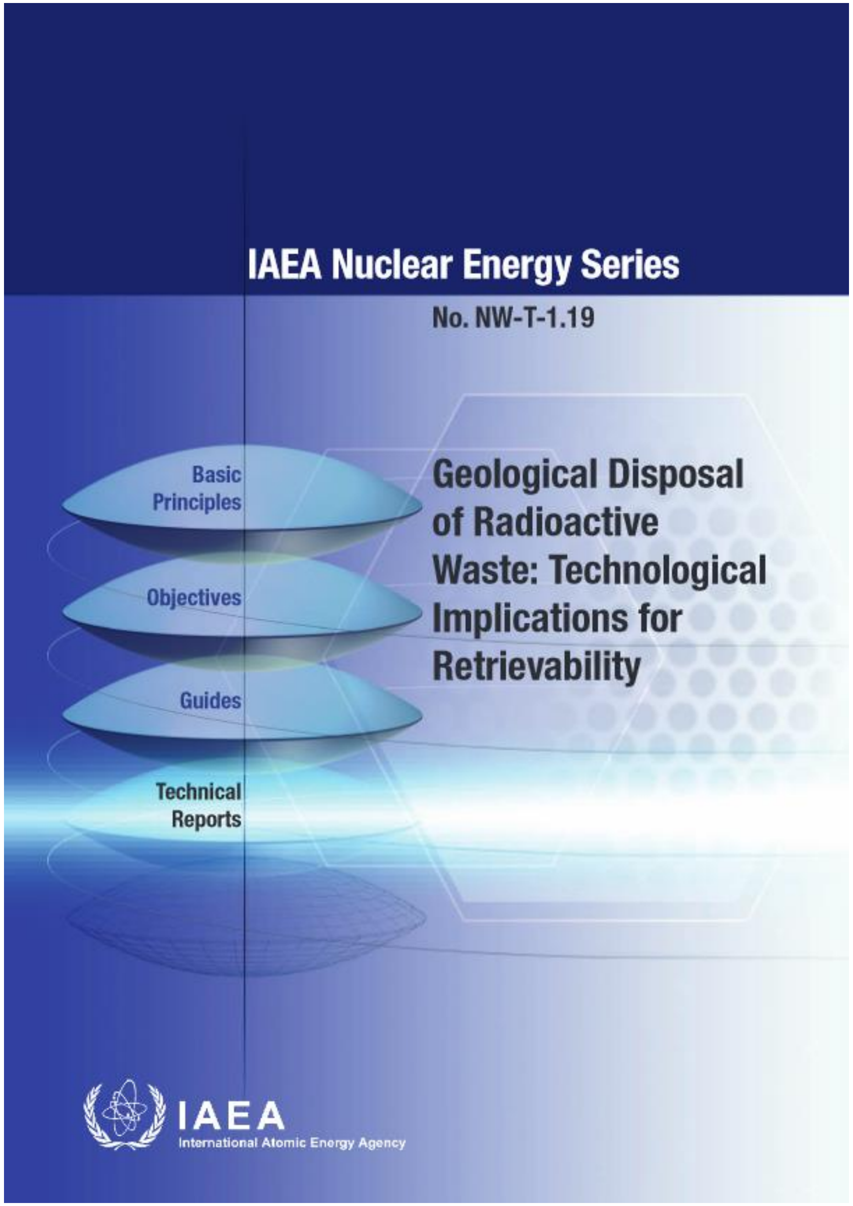


The aim of the current work is two-fold: to provide information on Pu sorption/desorption to/from industrial grade FEBEX bentonite, a potential repository backfill material, and to determine if the linearity observed for Pu(V) sorption to a pure Na-montmorillonite (Begg et al., 2013) extends to Pu(IV) sorption to a multi-component clay rock material. We investigate the sorption behavior of Pu(IV) to FEBEX bentonite across a wide range of initial

Clay backfill

"After vault backfilling, **retrieval of the waste packages would still be possible** [16], but additional equipment would be required and the retrieval would be more costly. Even after the repository is closed and sealed, the waste could be retrieved by conventional mining techniques."

- Retrieval process for UK's NIREX concept



IAEA Nuclear Energy Series

No. NW-T-1.19

Geological Disposal of Radioactive Waste: Technological Implications for Retrievability

Basic Principles

Objectives

Guides

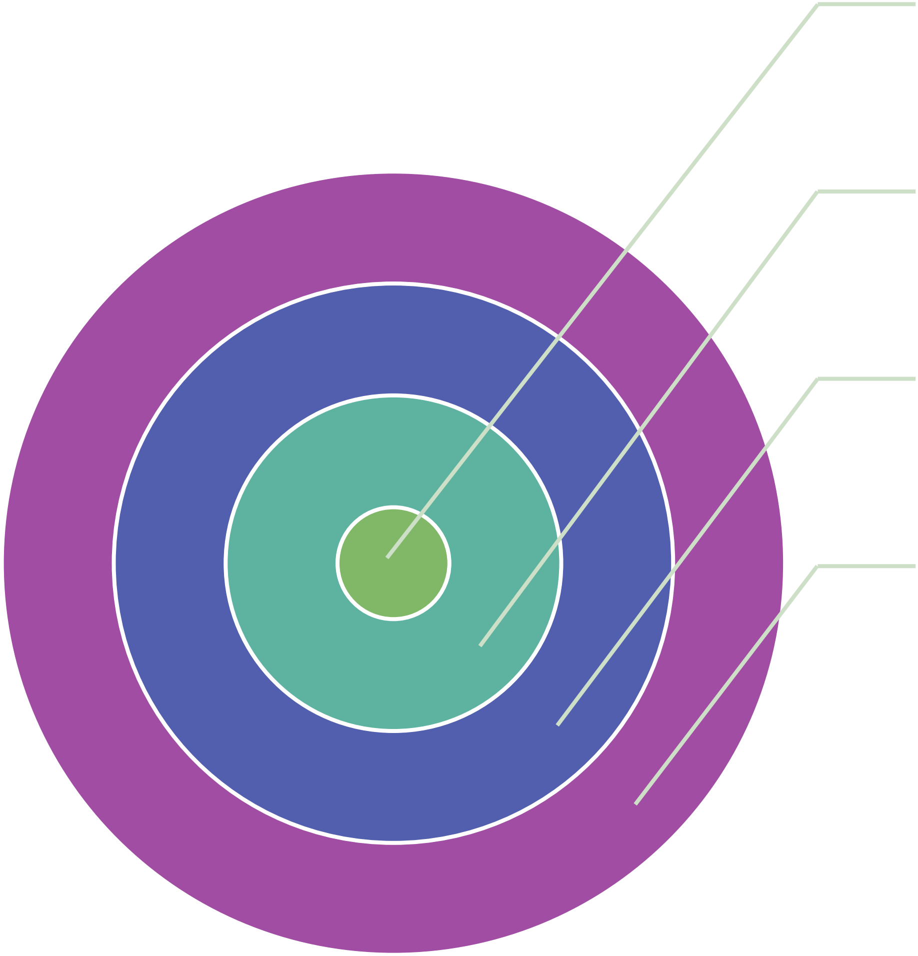
Technical Reports

IAEA

International Atomic Energy Agency

http://www-pub.iaea.org/MTCD/publications/PDF/Pub1378_web.pdf

Multi-Barrier Approach



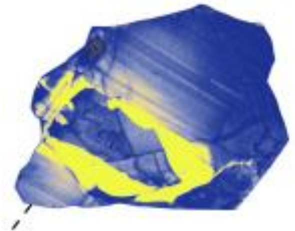
Waste Form

Canister

Overpack/Buffer/
Backfill

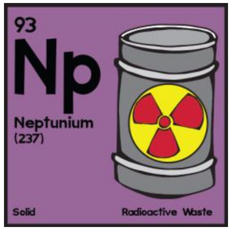
Repository

Why a geologic repository?



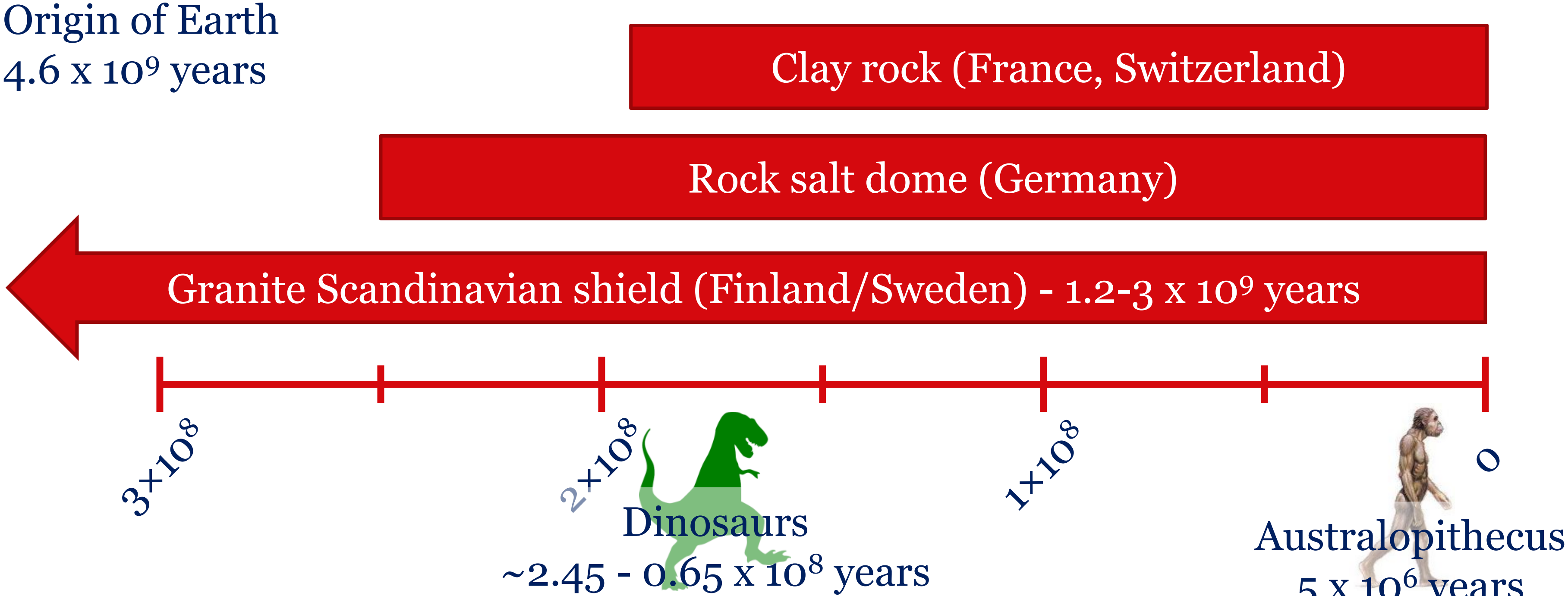
Oldest zircon crystal
4.4 x 10^9 years

Np-237 half life
2.1 x 10^6 years



Origin of Earth
4.6 x 10^9 years

Volcanic Tuff (USA) – last significant eruption **12 x 10^6** years



Clay rock (France, Switzerland)

Rock salt dome (Germany)

Granite Scandinavian shield (Finland/Sweden) - 1.2-3 x 10^9 years

Dinosaurs
~2.45 - 0.65 x 10^8 years

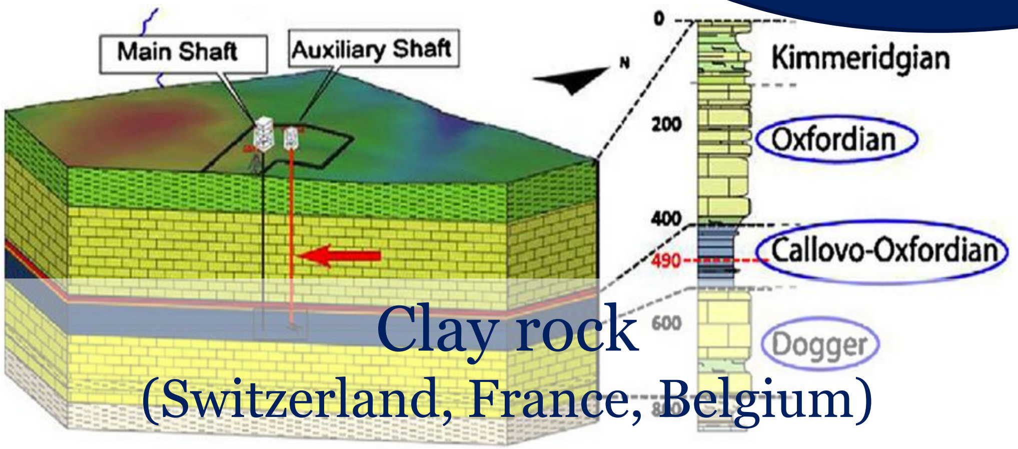
Australopithecus
5 x 10^6 years

Country	Geologic formations	Indigenous underground research laboratory
US	Salt, basalt, granite, tuff, clay, shale	Exploratory studies facility at YM served function of underground laboratory (tuff)
Belgium	Clay, shale	Mol (clay)
Canada	Granite, sedimentary	Pinawa (granite)*
China	Granite	None
Finland	Granite, gneiss, grandiorite, migmatite	Construction of ONKALO underground facility in Eurajoki began in 2004 (granite)
France	Argillite, granite	Bure (argillite)
Germany	Salt	Gorleben (salt)
Japan	Granite, sedimentary	Tona (granite), Mizunami (granite), Horonaobe (sedimentary rock)
Korea	Granite	Korea Underground Research Tunnel (shallow)
Spain	Granite, clay, salt	None
Sweden	Granite	Aspo (granite)
Switzerland	Clay, granite	More Terri (clay), Grirael (granite)
UK	No decision made.	None

Geologic Formations

Granite
(Sweden, Finland, Canada)

Volcanic Tuff
(USA)



Clay rock
(Switzerland, France, Belgium)

Rock salt
(USA, Germany)

Clay Rock

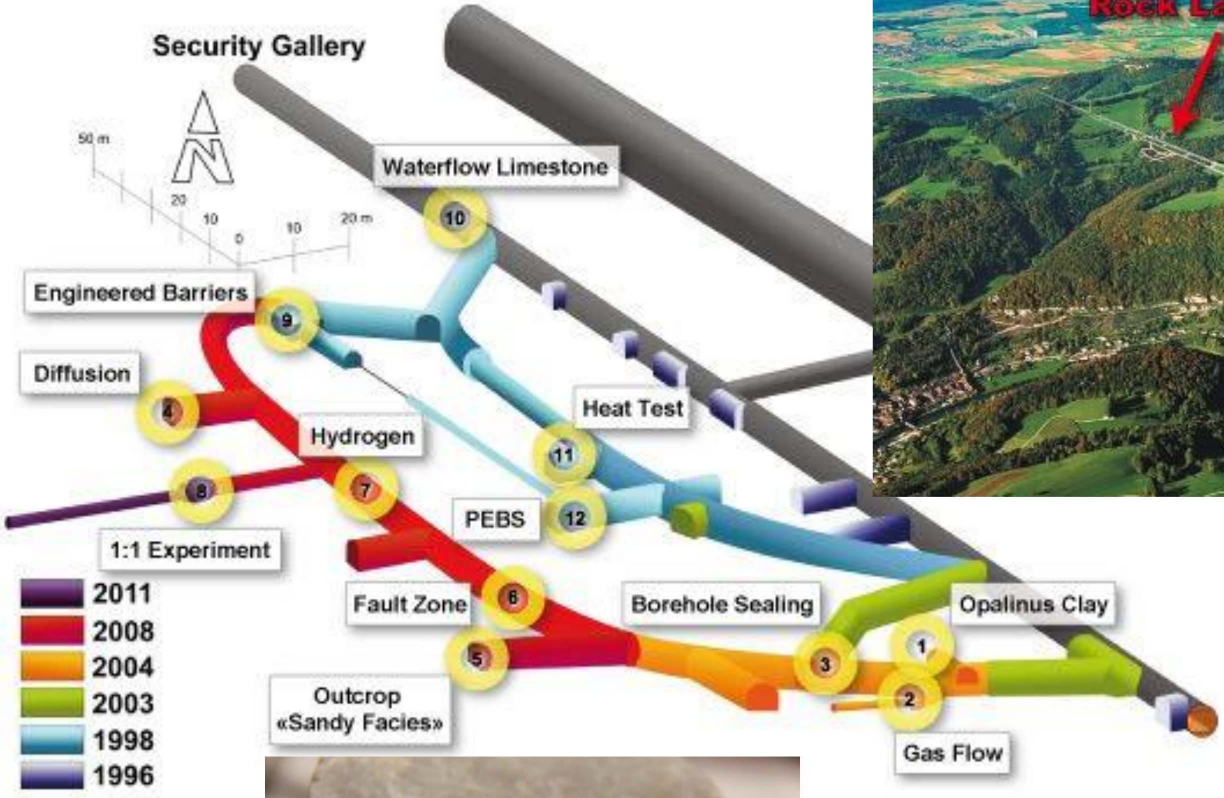
Advantages

- Tightness
- Plasticity (swelling capacity)
- Low solubility
- High sorption capacity

Disadvantages

- Low heat conductivity
- Low temp. resistance
- Difficult mine construction
  - Damage zone around excavation
  - Oil drill holes common

Mont Terri Rock Laboratory



Core of the Opalinus Clay
showing the signature ammonite.

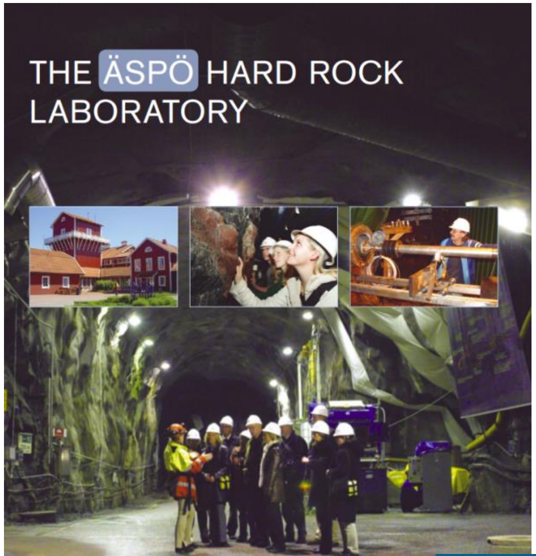
Granite

Advantages

- Mechanically stable
- Age of rock formation
- Moderate heat conductivity
- Good state of knowledge

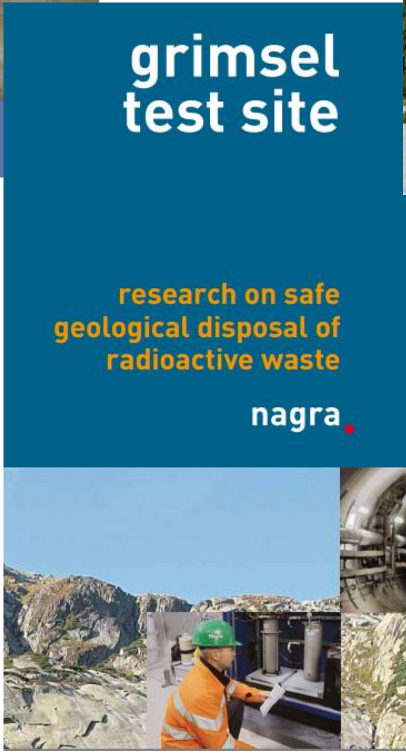
Disadvantages

- Water bearing fractures
- Moderate retention capacity
- Technical barriers imperative (bentonite, copper canister)
  - Low temperature resistance



THE ÄSPÖ HARD ROCK LABORATORY

SKB



grimsel test site

research on safe geological disposal of radioactive waste

nagra.

August 2004

ONKALO underground rock characterization facility (Finland)

Summer 2014

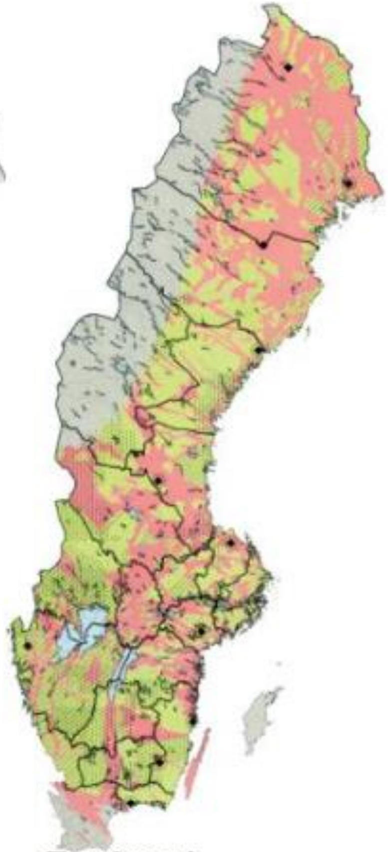
Pinawa underground facility (Canada)

1983 - Construction begins
1985 – Research begins
1998 – Decommissioning begins
2010 – Final closure

Winnipeg Free Press

Sweden’s Hard Rock Adventure: Siting studies (1977-2001)

Study sites 1977-1985



Regional studies 1987-1989

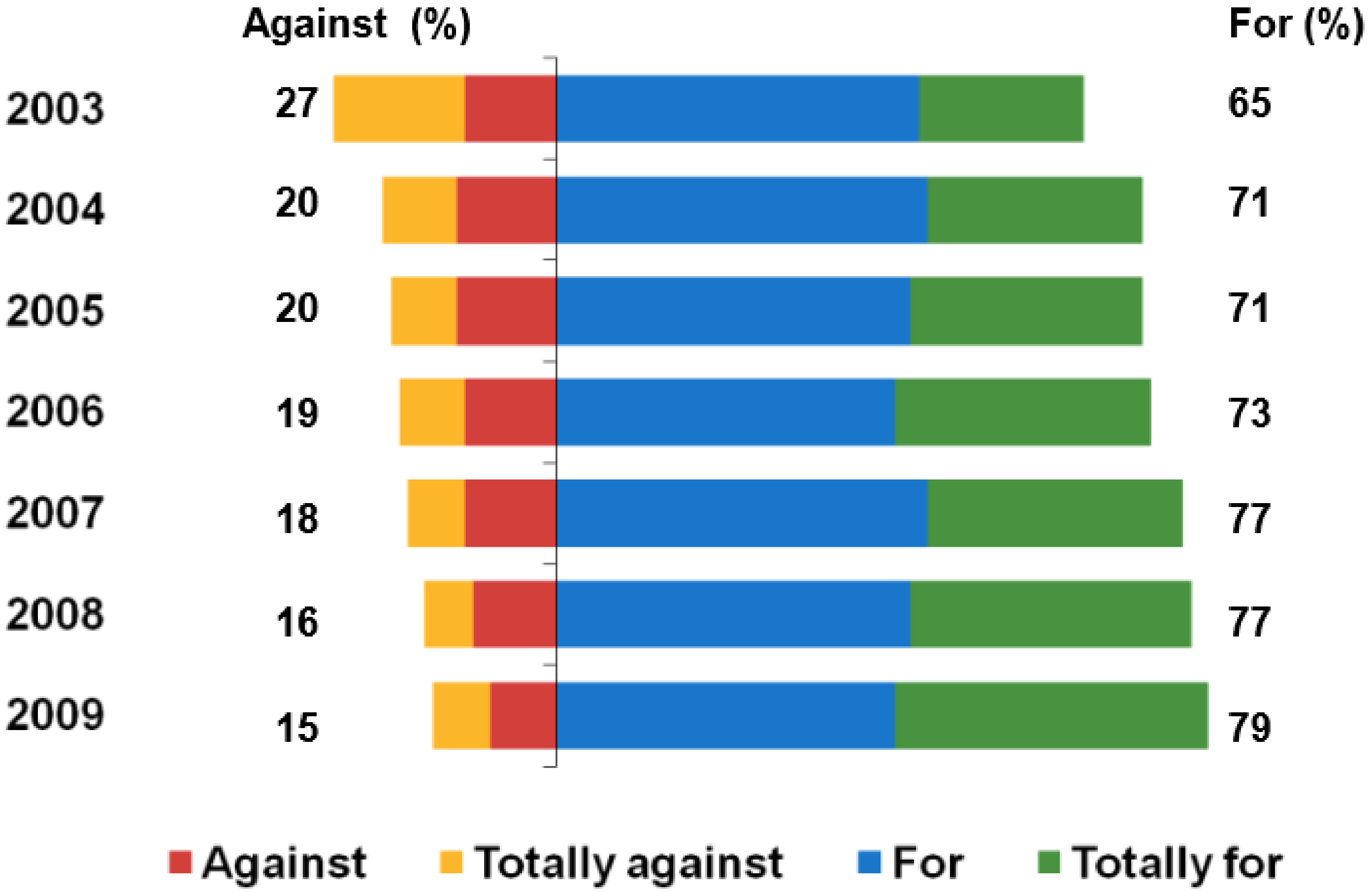
Feasibility studies 1992-2001

2002-2007
Limited investigation to Forsmark & Oskarshamn

2009
SKB selected Forsmark

Modified from Claes Thegerström

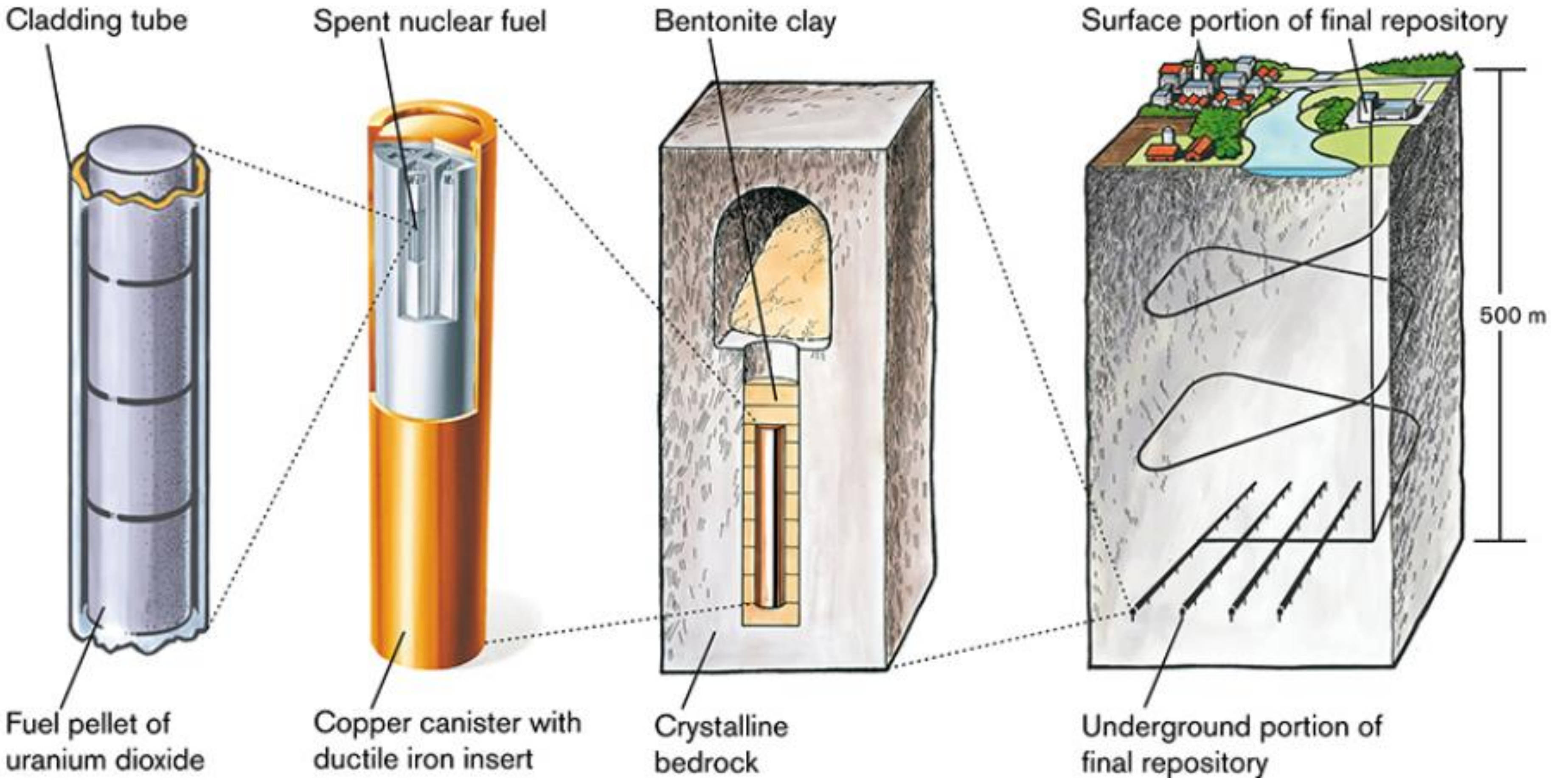
Sweden’s Hard Rock Adventure:
Strong local support for the Forsmark



The poll 2009
was taken in
April and May,
i.e.before
SKB announced
its site selection
on June 3

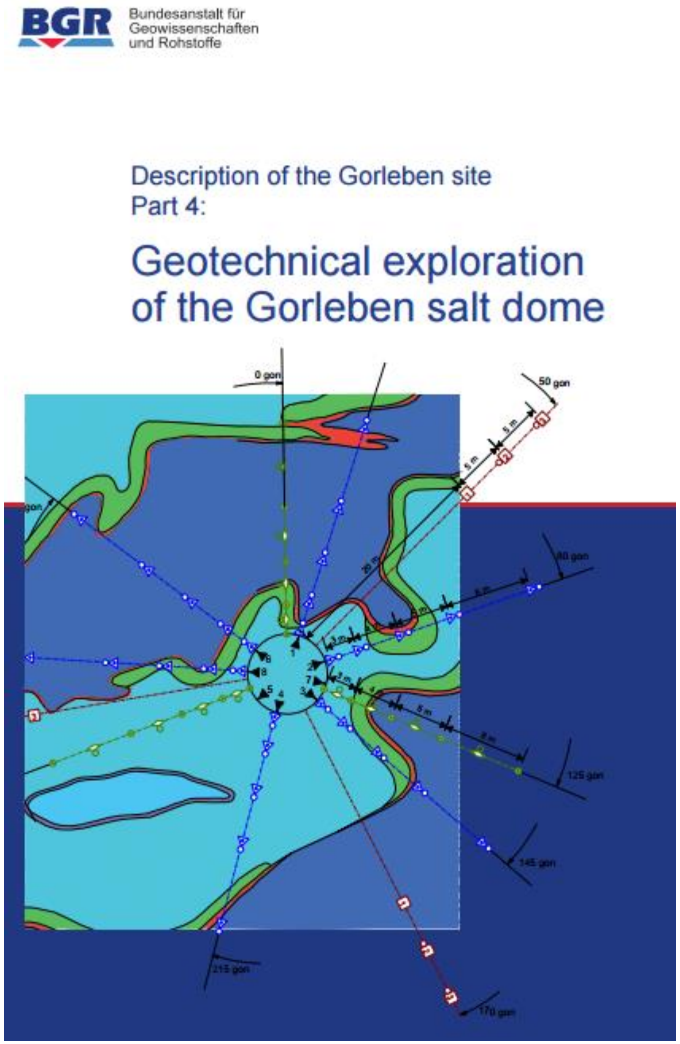
Modified from Claes Thegerström

Sweden's Hard Rock Adventure: The KBS-3 design



Rock salt

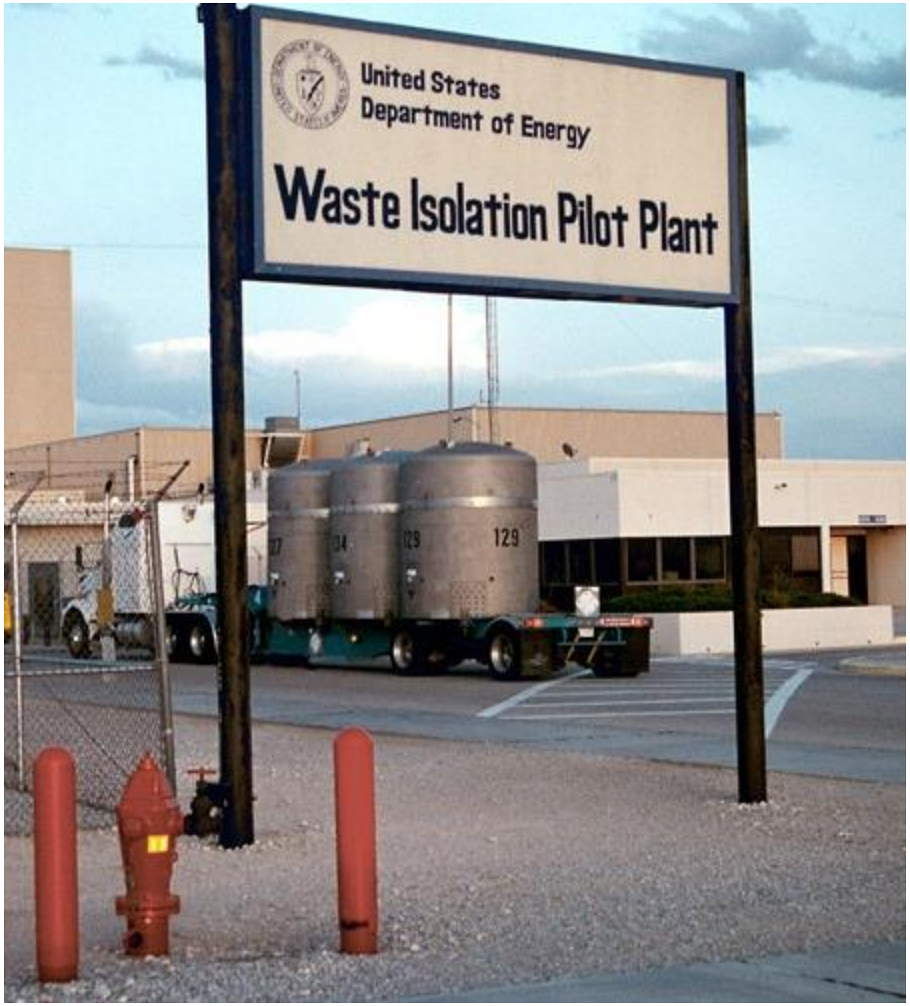
Advantages	**Disadvantages**
Tightness	Water soluble
Plasticity (convergence)	Low retention capacity
Heat conductive	Dissolution
High temp. resistance	Uplift (~ 0.02 mm/yr)
Age of existing diapirs	
Good state of knowledge	



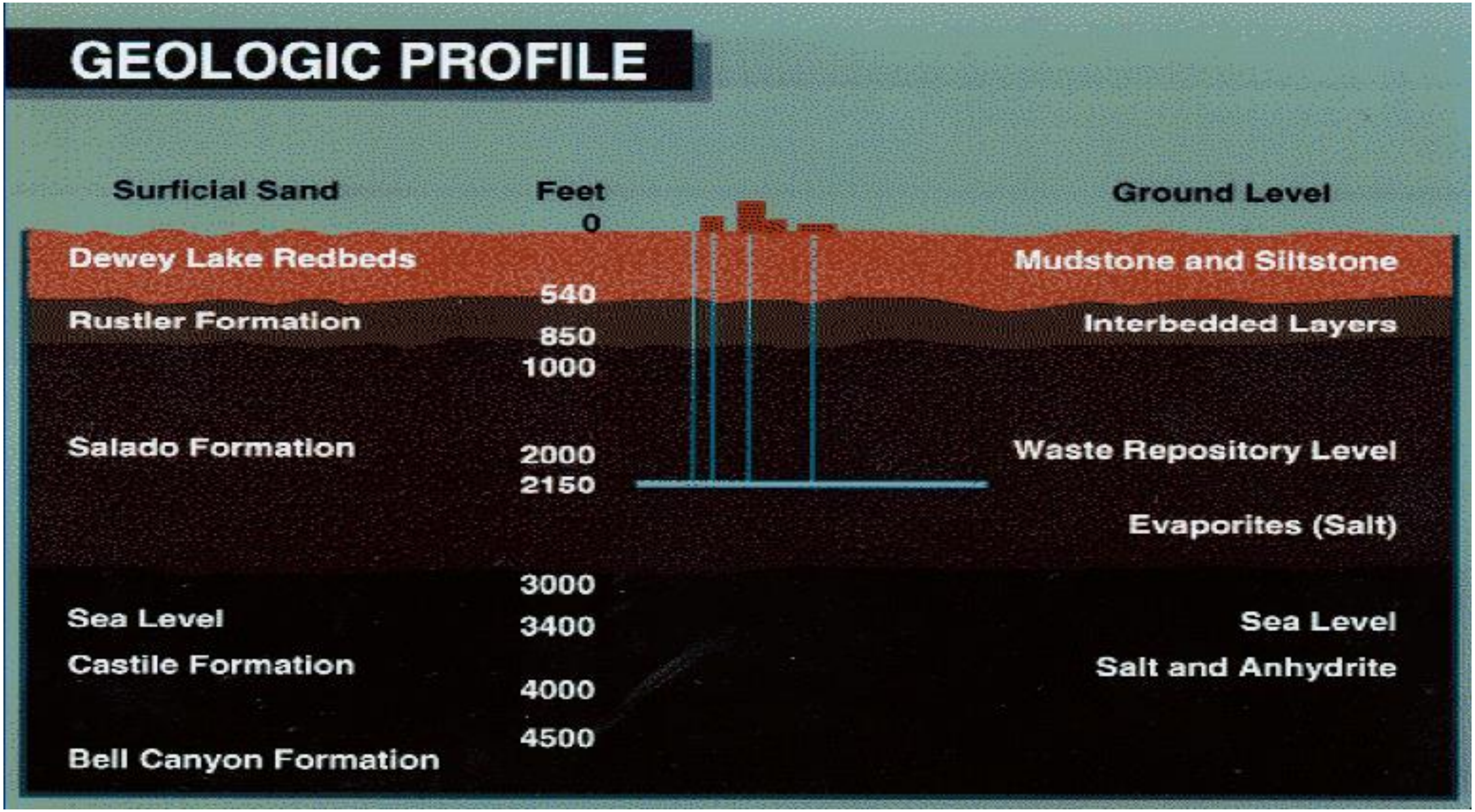
BGR Bundesanstalt für Geowissenschaften und Rohstoffe

Description of the Gorleben site
Part 4:

Geotechnical exploration
of the Gorleben salt dome



Salt formations at WIPP were deposited in thick beds during the evaporation of the Permian Sea.



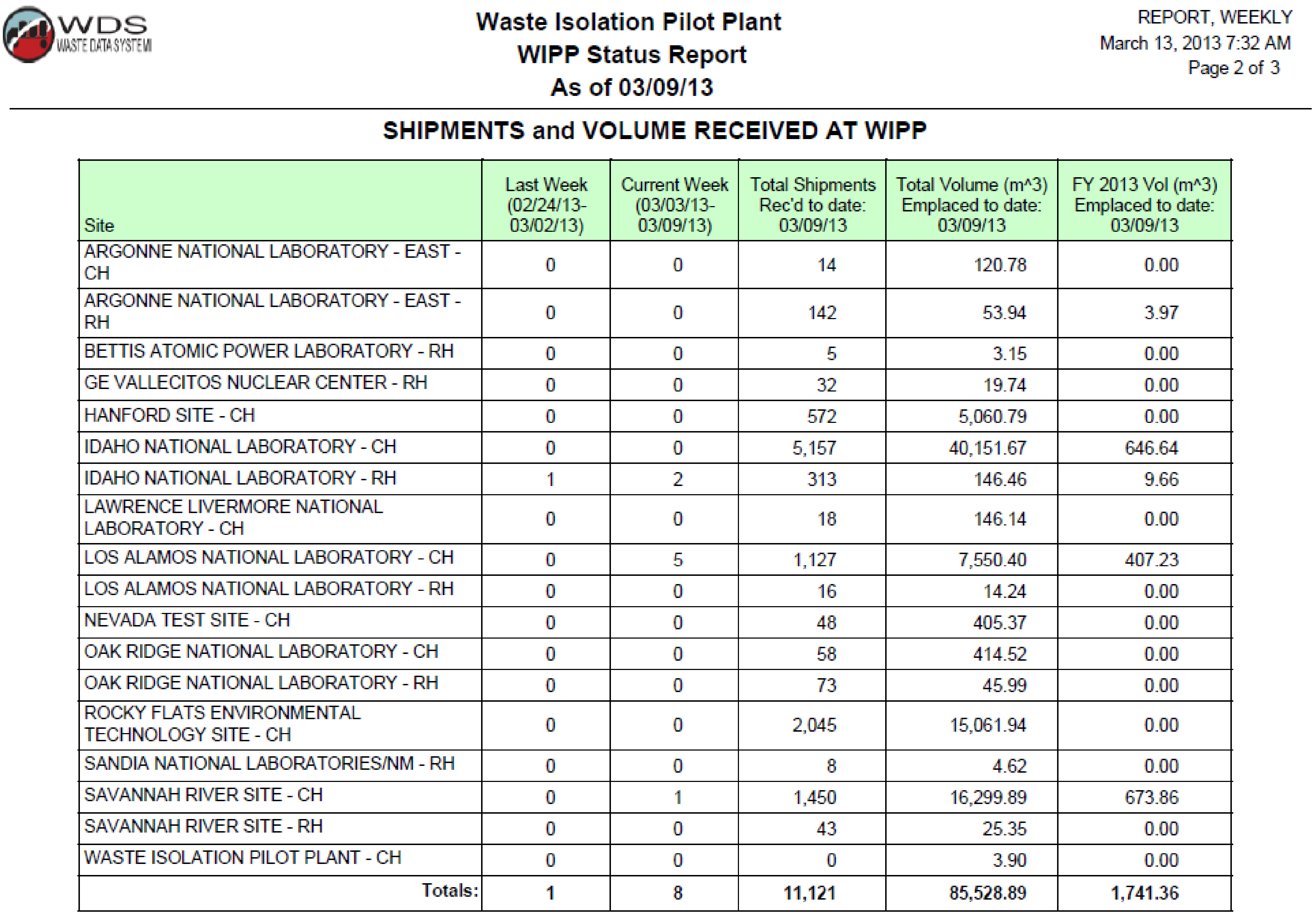
Hydrocarbons, potash, and possibly natural gas exist under WIPP or in the area.

March 26, 1999 – waste disposal operations begin

http://www.wipp.energy.gov/Video/w1.mpg

Shipments Received (as of February 11, 2014)

Site	Shipments	Loaded Miles
ANL	193	331,333
Bettis Atomic Power Lab	5	10,955
GE Vallecitos Nuclear Center	32	44,800
INL	5,844	8,132,064
LANL	1,344	459,648
LLNL	18	24,804
Nevada Test Site	48	57,312
ORNL	131	175,933
Rocky Flats	2,045	1,446,444
Hanford Site	572	1,034,176
SNL	8	2,200
Savannah River Site	1,654	2,483,360
Total to WIPP	**11,894**	**14,203,029**



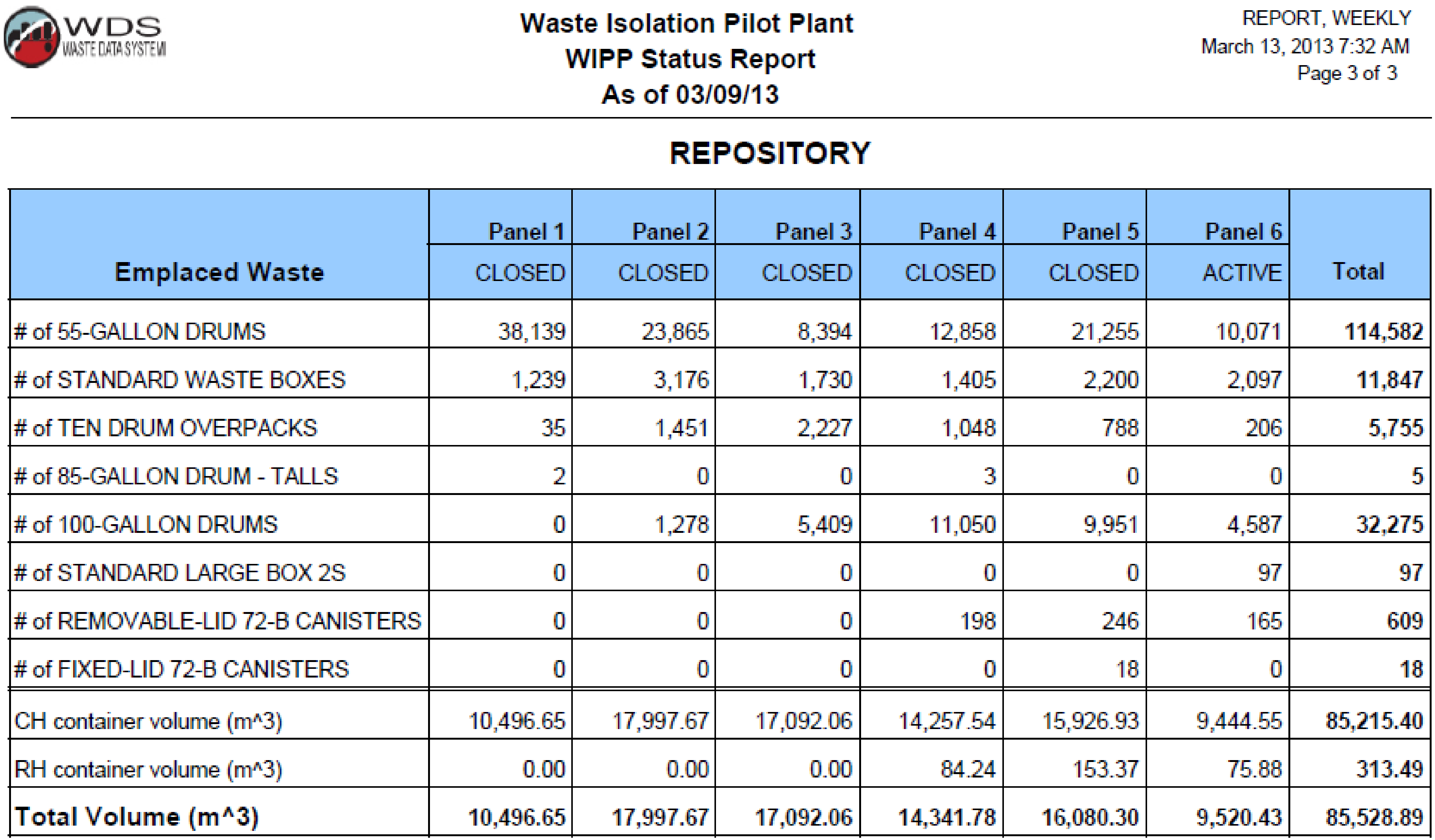
WDS
WASTE DATA SYSTEM

Waste Isolation Pilot Plant
WIPP Status Report
As of 03/09/13

REPORT, WEEKLY
March 13, 2013 7:32 AM
Page 2 of 3

SHIPMENTS and VOLUME RECEIVED AT WIPP

Site	Last Week (02/24/13-03/02/13)	Current Week (03/03/13-03/09/13)	Total Shipments Rec'd to date: 03/09/13	Total Volume (m^3) Emplaced to date: 03/09/13	FY 2013 Vol (m^3) Emplaced to date: 03/09/13
ARGONNE NATIONAL LABORATORY - EAST - CH	0	0	14	120.78	0.00
ARGONNE NATIONAL LABORATORY - EAST - RH	0	0	142	53.94	3.97
BETTIS ATOMIC POWER LABORATORY - RH	0	0	5	3.15	0.00
GE VALLECITOS NUCLEAR CENTER - RH	0	0	32	19.74	0.00
HANFORD SITE - CH	0	0	572	5,060.79	0.00
IDAHO NATIONAL LABORATORY - CH	0	0	5,157	40,151.67	646.64
IDAHO NATIONAL LABORATORY - RH	1	2	313	146.46	9.66
LAWRENCE LIVERMORE NATIONAL LABORATORY - CH	0	0	18	146.14	0.00
LOS ALAMOS NATIONAL LABORATORY - CH	0	5	1,127	7,550.40	407.23
LOS ALAMOS NATIONAL LABORATORY - RH	0	0	16	14.24	0.00
NEVADA TEST SITE - CH	0	0	48	405.37	0.00
OAK RIDGE NATIONAL LABORATORY - CH	0	0	58	414.52	0.00
OAK RIDGE NATIONAL LABORATORY - RH	0	0	73	45.99	0.00
ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE - CH	0	0	2,045	15,061.94	0.00
SANDIA NATIONAL LABORATORIES/NM - RH	0	0	8	4.62	0.00
SAVANNAH RIVER SITE - CH	0	1	1,450	16,299.89	673.86
SAVANNAH RIVER SITE - RH	0	0	43	25.35	0.00
WASTE ISOLATION PILOT PLANT - CH	0	0	0	3.90	0.00
Totals:	**1**	**8**	**11,121**	**85,528.89**	**1,741.36**



WDS
WASTE DATA SYSTEM

Waste Isolation Pilot Plant
WIPP Status Report
As of 03/09/13

REPORT, WEEKLY
March 13, 2013 7:32 AM
Page 3 of 3

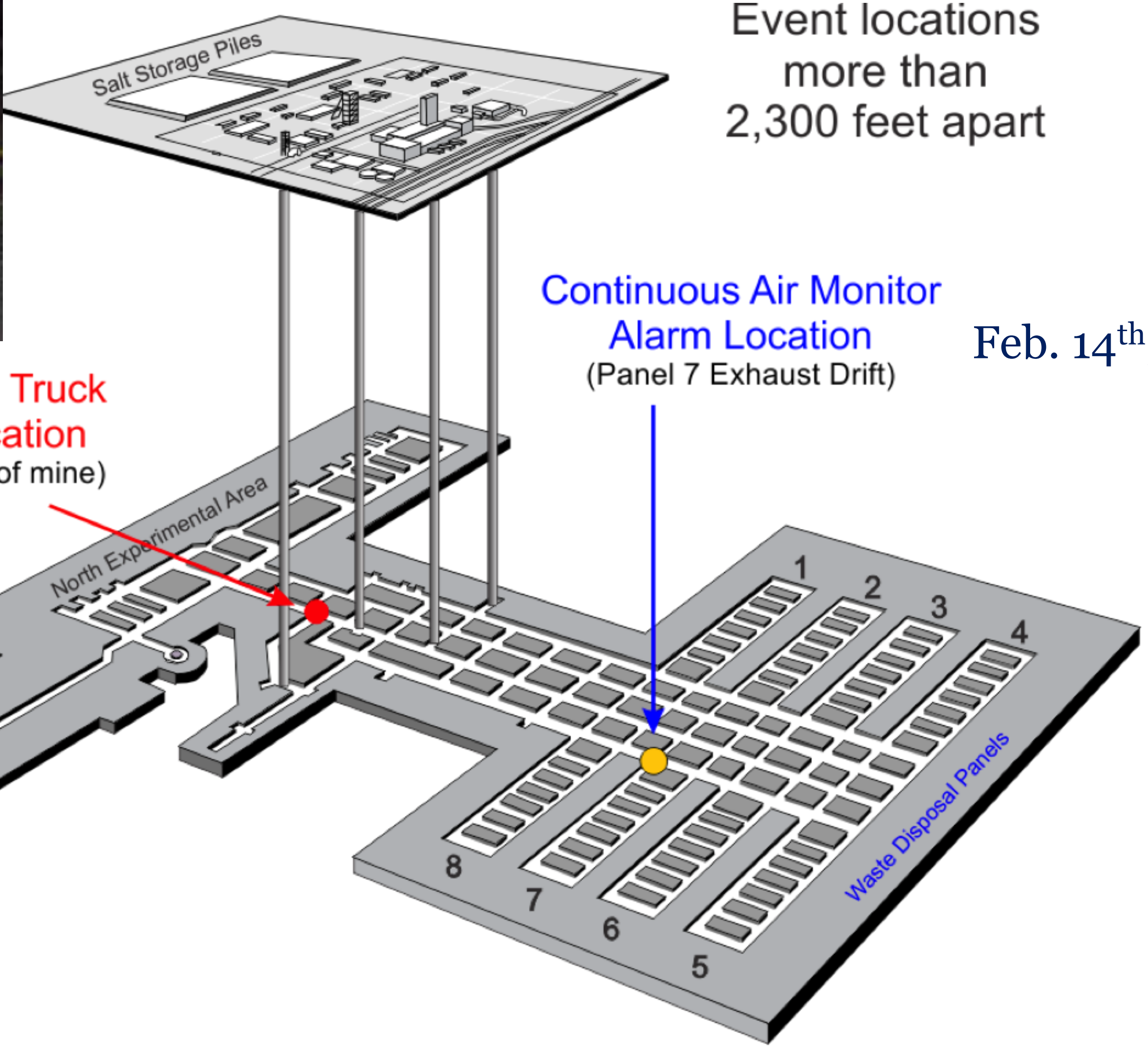
REPOSITORY

Emplaced Waste	Panel 1	Panel 2	Panel 3	Panel 4	Panel 5	Panel 6	Total
	CLOSED	CLOSED	CLOSED	CLOSED	CLOSED	ACTIVE	
# of 55-GALLON DRUMS	38,139	23,865	8,394	12,858	21,255	10,071	**114,582**
# of STANDARD WASTE BOXES	1,239	3,176	1,730	1,405	2,200	2,097	**11,847**
# of TEN DRUM OVERPACKS	35	1,451	2,227	1,048	788	206	**5,755**
# of 85-GALLON DRUM - TALLS	2	0	0	3	0	0	**5**
# of 100-GALLON DRUMS	0	1,278	5,409	11,050	9,951	4,587	**32,275**
# of STANDARD LARGE BOX 2S	0	0	0	0	0	97	**97**
# of REMOVABLE-LID 72-B CANISTERS	0	0	0	198	246	165	**609**
# of FIXED-LID 72-B CANISTERS	0	0	0	0	18	0	**18**
CH container volume (m^3)	10,496.65	17,997.67	17,092.06	14,257.54	15,926.93	9,444.55	**85,215.40**
RH container volume (m^3)	0.00	0.00	0.00	84.24	153.37	75.88	**313.49**
Total Volume (m^3)	**10,496.65**	**17,997.67**	**17,092.06**	**14,341.78**	**16,080.30**	**9,520.43**	**85,528.89**

http://www.wipp.energy.gov/general/GenerateWippStatusReport.pdf

Waste Isolation Pilot Plant February 2014

Feb. 5th, 2014



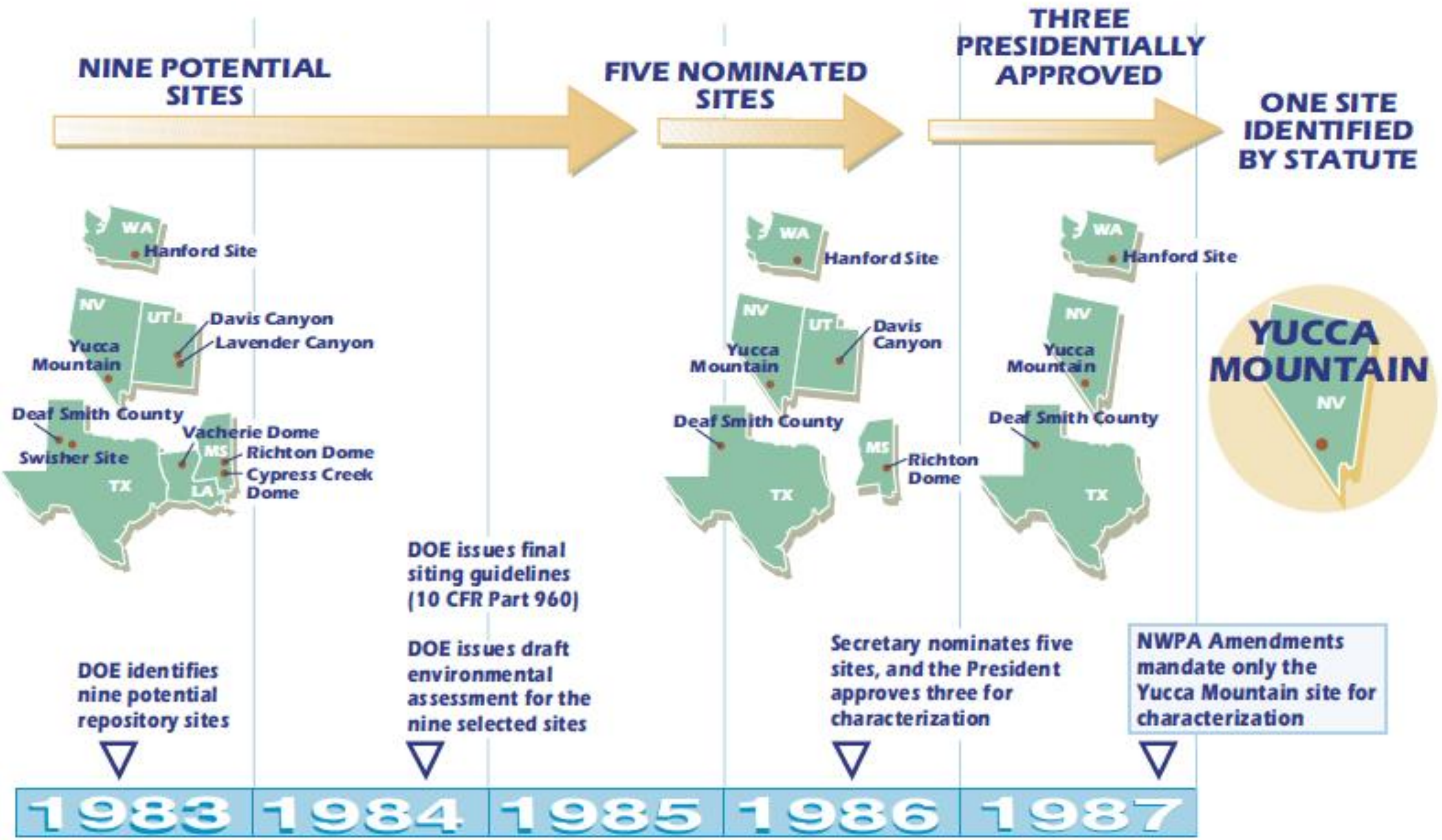
Event locations
more than
2,300 feet apart

Salt Haul Truck
Fire Location
(North part of mine)

Continuous Air Monitor
Alarm Location
(Panel 7 Exhaust Drift)

Feb. 14th, 2014

What about civilian waste in the US?



NINE POTENTIAL SITES

FIVE NOMINATED SITES

THREE PRESIDENTIALLY APPROVED

ONE SITE IDENTIFIED BY STATUTE

DOE identifies nine potential repository sites

DOE issues final siting guidelines (10 CFR Part 960)

DOE issues draft environmental assessment for the nine selected sites

Secretary nominates five sites, and the President approves three for characterization

NWPA Amendments mandate only the Yucca Mountain site for characterization

What sets YM apart from all other repositories?

- Above water table → oxidizing
  - take advantage of heat generating waste to drive off water
  - capacity limited based on heat distribution
  - additional engineered barrier (Ti drip shield)

reducing

uraninite (UO_{2+x})

oxidizing

coffinite
$USiO_4$

rutherfordine
metaschoepite becquerelite
autunite
sklodowskite studtite
uranophane weeksite
zippeite soddyite
torbernite clarkeite
schoepite
boltwoodite

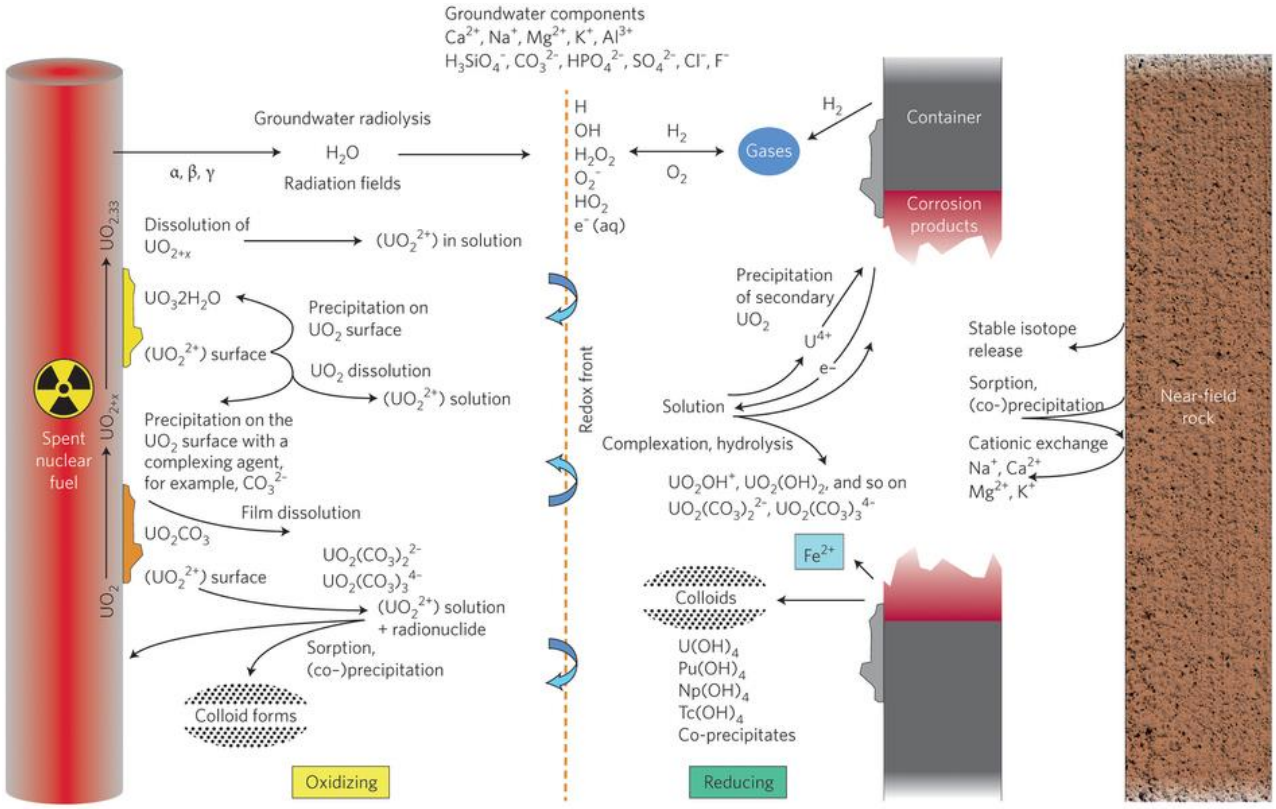
The intersect of science and policy → makes nuclear waste disposal even more challenging

- Some political/societal challenges that impact repository design:
  - Location
  - Retreivability
  - Nonproliferation/Safeguards
  - Safety (in terms of accidental or eventual release)

- Educated decisions require sound scientific basis

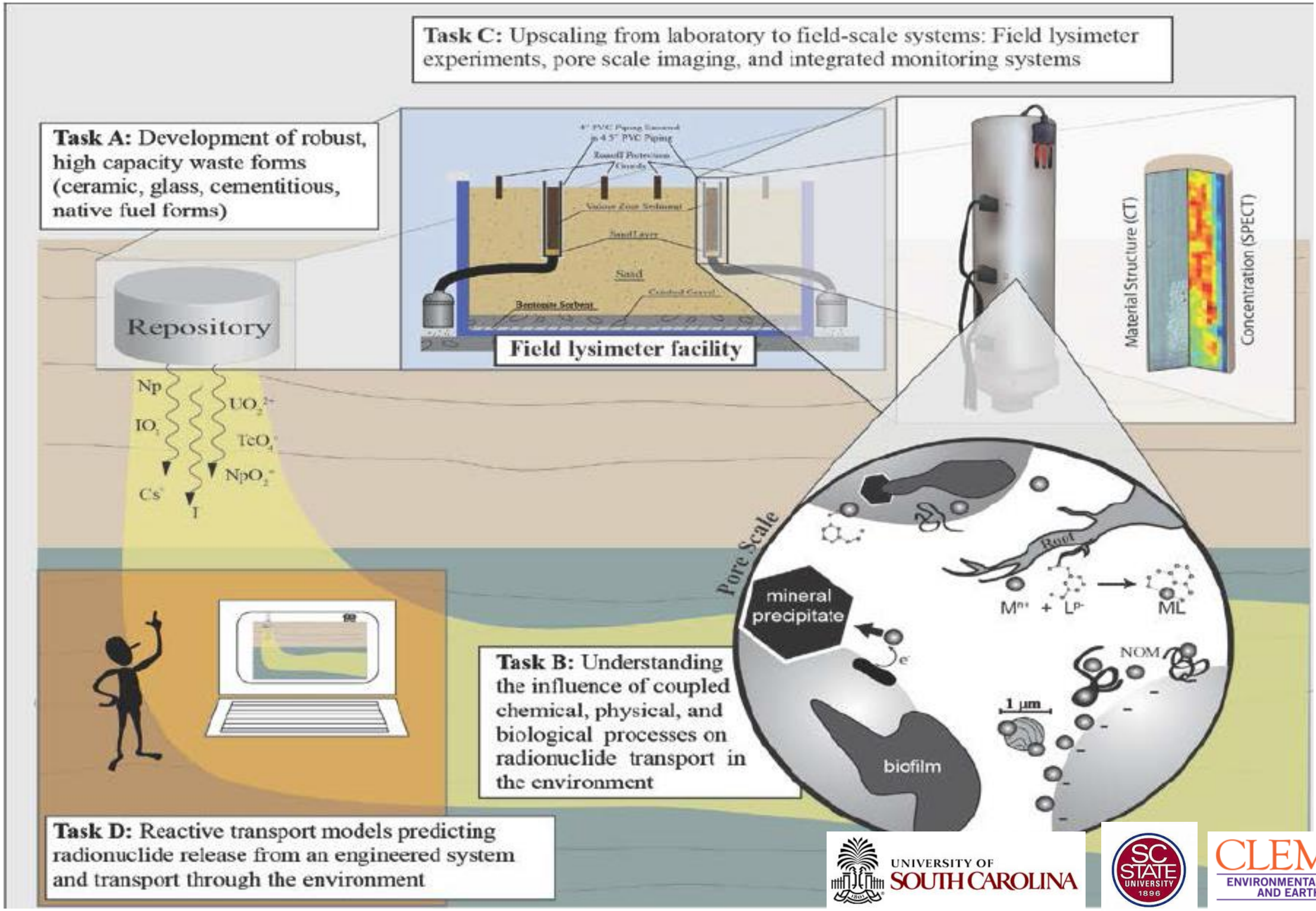
We still need to uncover many scientific uncertainties…

Knowledge gaps remain that make **predicting the fate and transport of RNs** in the near field and far field of a repository challenging



Ewing *Nature Materials* 2015

Integrated science/engineering approach to fate and transport of RN in the environment



Task C: Upscaling from laboratory to field-scale systems: Field lysimeter experiments, pore scale imaging, and integrated monitoring systems

Task A: Development of robust, high capacity waste forms (ceramic, glass, cementitious, native fuel forms)

Task B: Understanding the influence of coupled chemical, physical, and biological processes on radionuclide transport in the environment

Task D: Reactive transport models predicting radionuclide release from an engineered system and transport through the environment

UNIVERSITY OF SOUTH CAROLINA

SC STATE UNIVERSITY 1896

CLEMSON ENVIRONMENTAL ENGINEERING AND EARTH SCIENCES

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References for Figures/Videos

- Slide 2 - http://science.bennington.edu/?author=11; http://iss.unige.ch/content/phd-thesis-defense-nizar-ghoula; http://co2.egi.utah.edu/
- Slide 5 – www.nei.org
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- Slide 34 - https://www.youtube.com/watch?v=1eJMY9MT4a8&feature=youtu.be&t=11
- Slide 44 – modified from H. Gekeis
- Slides 51-52 – modified from C. Thegerström
- Slide 53 - http://www.skb.com/future-projects/the-spent-fuel-repository/our-methodology/
- Slide 57 - http://www.wipp.energy.gov/Video/w1.mpg
- Slide 66 - Clemson University EPSCoR Implementation grant

Upcoming Webinars

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NAMP website: www.wipp.energy.gov/namp