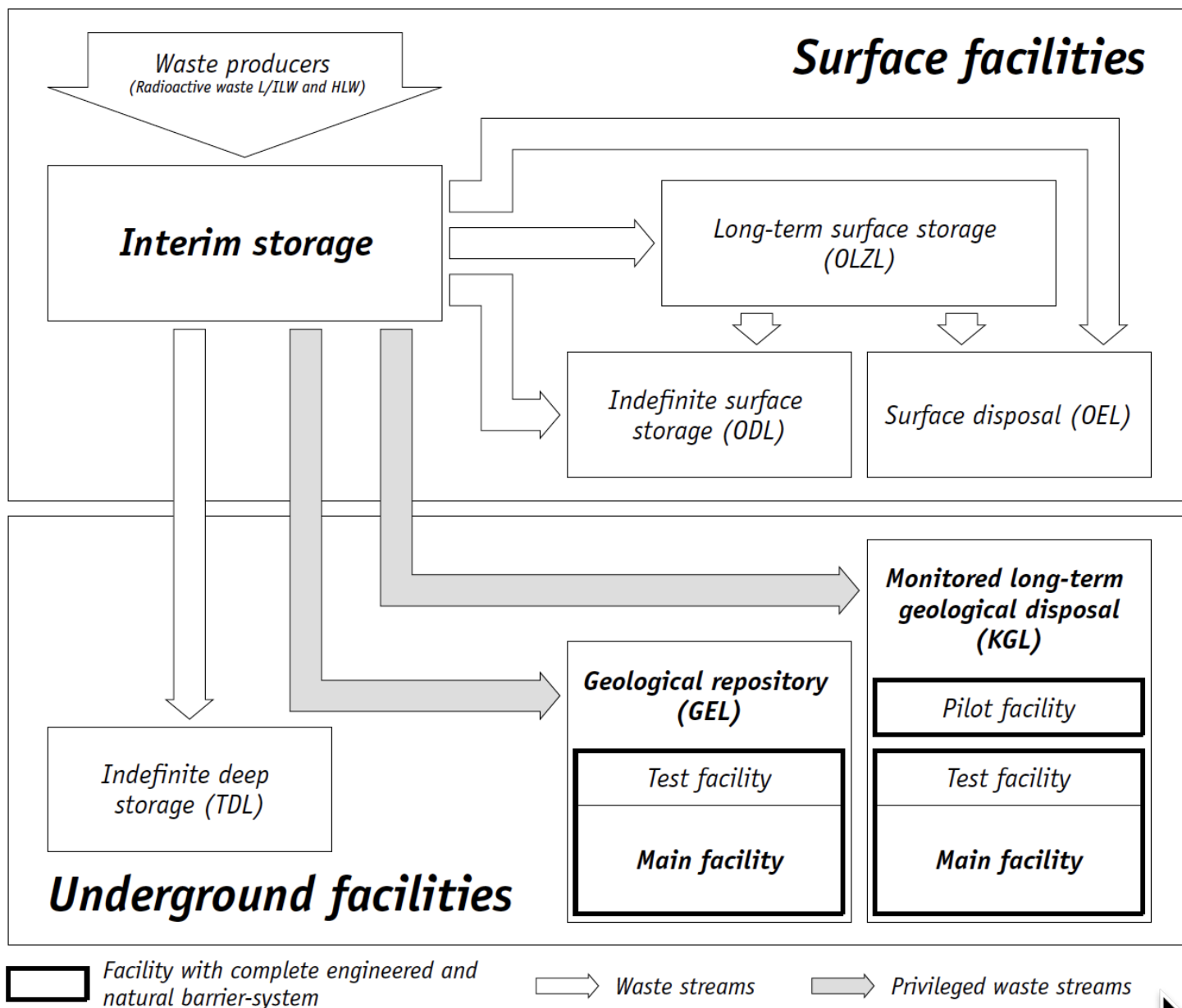


Danish Ministry of Higher Education and Science

„Repository for low- and intermediate-level waste: the planning of a complex scientific and technical challenge“

Copenhagen, 6th February 2019

Marcos Buser
Geologist & social scientist, INA Ltd., Zürich



Early warnings related to social acceptance and technical feasibility reported by Alvin Weinberg, former director of Oak Ridge National Laboratory



Enrico Fermi, physicist, Nobel price 1938, creator of the first nuclear reactor CP-1, 1944

„It is not clear, that the public will accept an energy source that produces this much radioactivity and that can be subjected to diversion of materials for bombs.“

Alvin Weinberg, The First Nuclear Era, The Life and Times of a Technological Fixer, AIP Press, p. 40-41



James B. Conant, chemist, director of the National Defense Research Committee, President of Harvard University, 1951:

Nuclear energy would „not be worth a candle“ because the problem of radioactive waste was intractable.

Alvin Weinberg, The First Nuclear Era, The Life and Times of a Technological Fixer, AIP Press, p. 77

Content

A look back

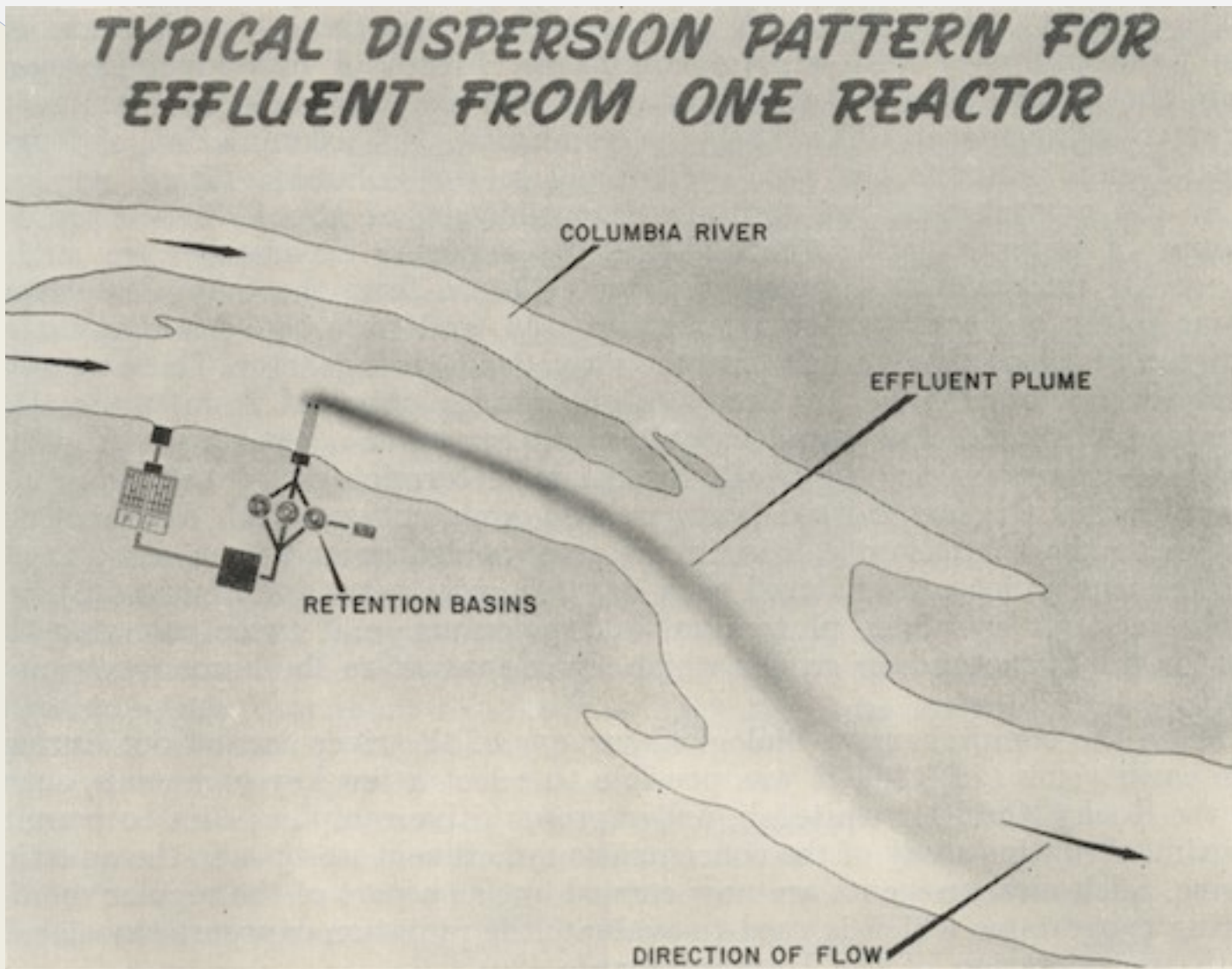
- some examples of disposal practices
- failures & interpretations

A look forwards

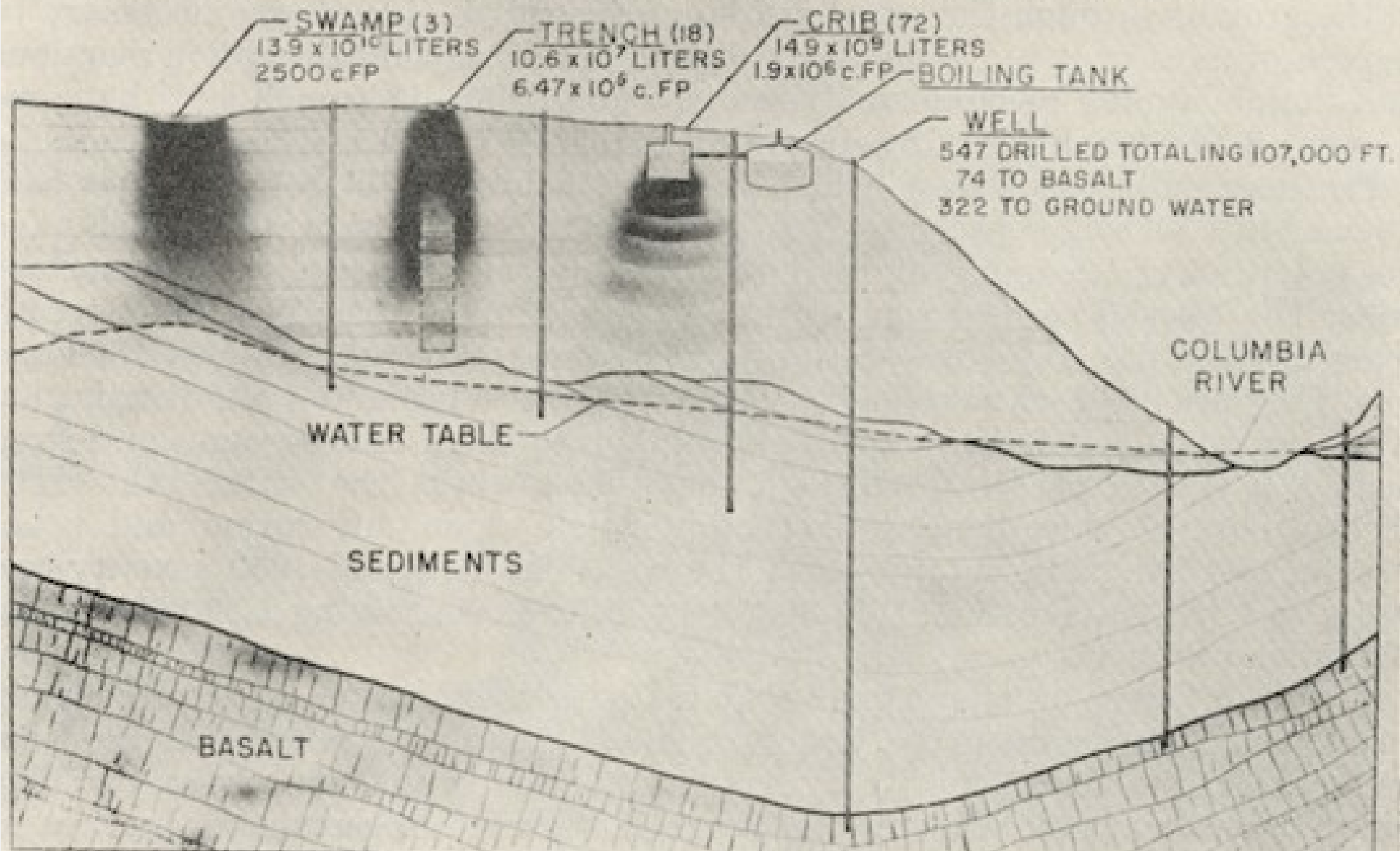
- key issues
- ways to deal with complexity

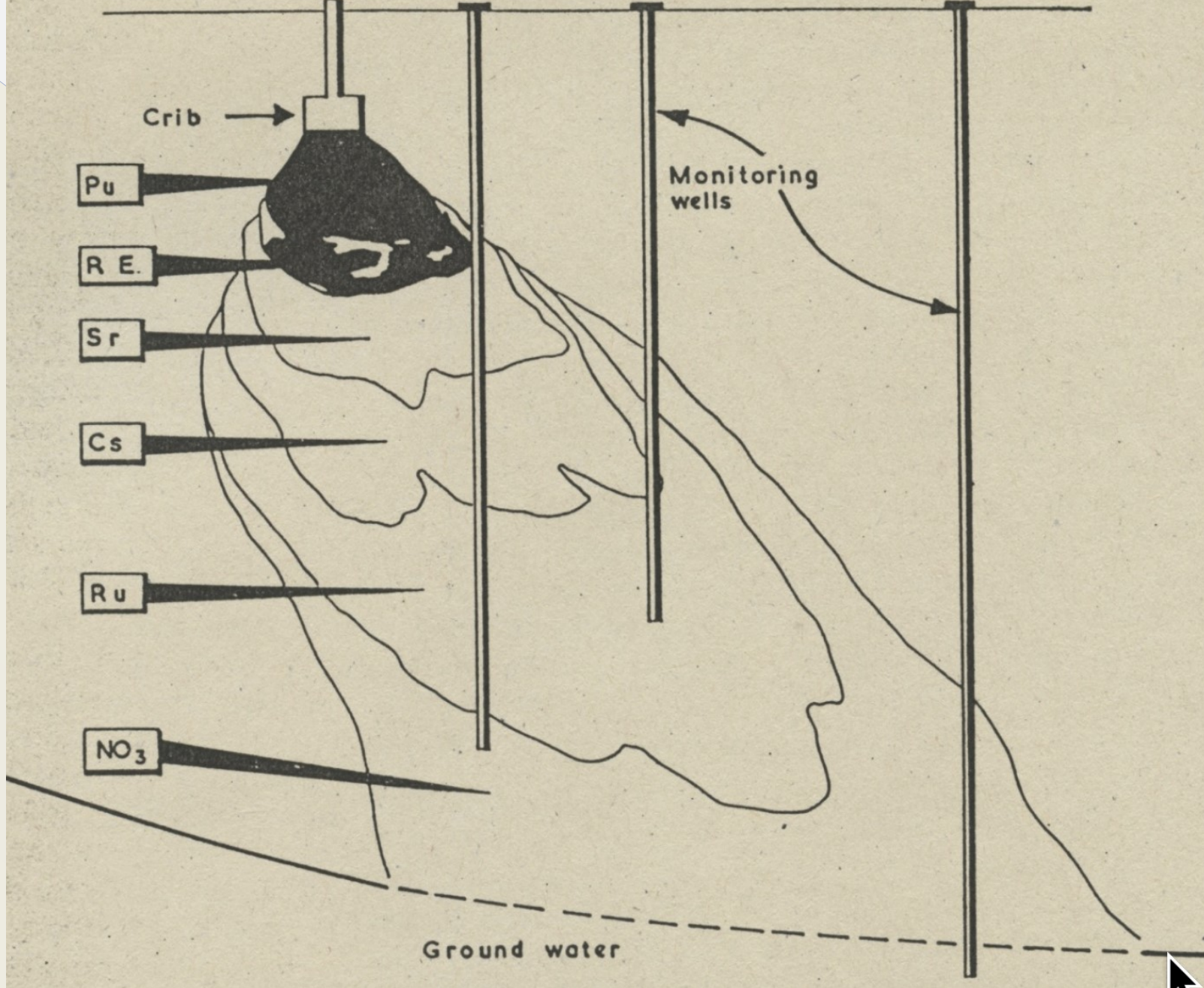
Outlook

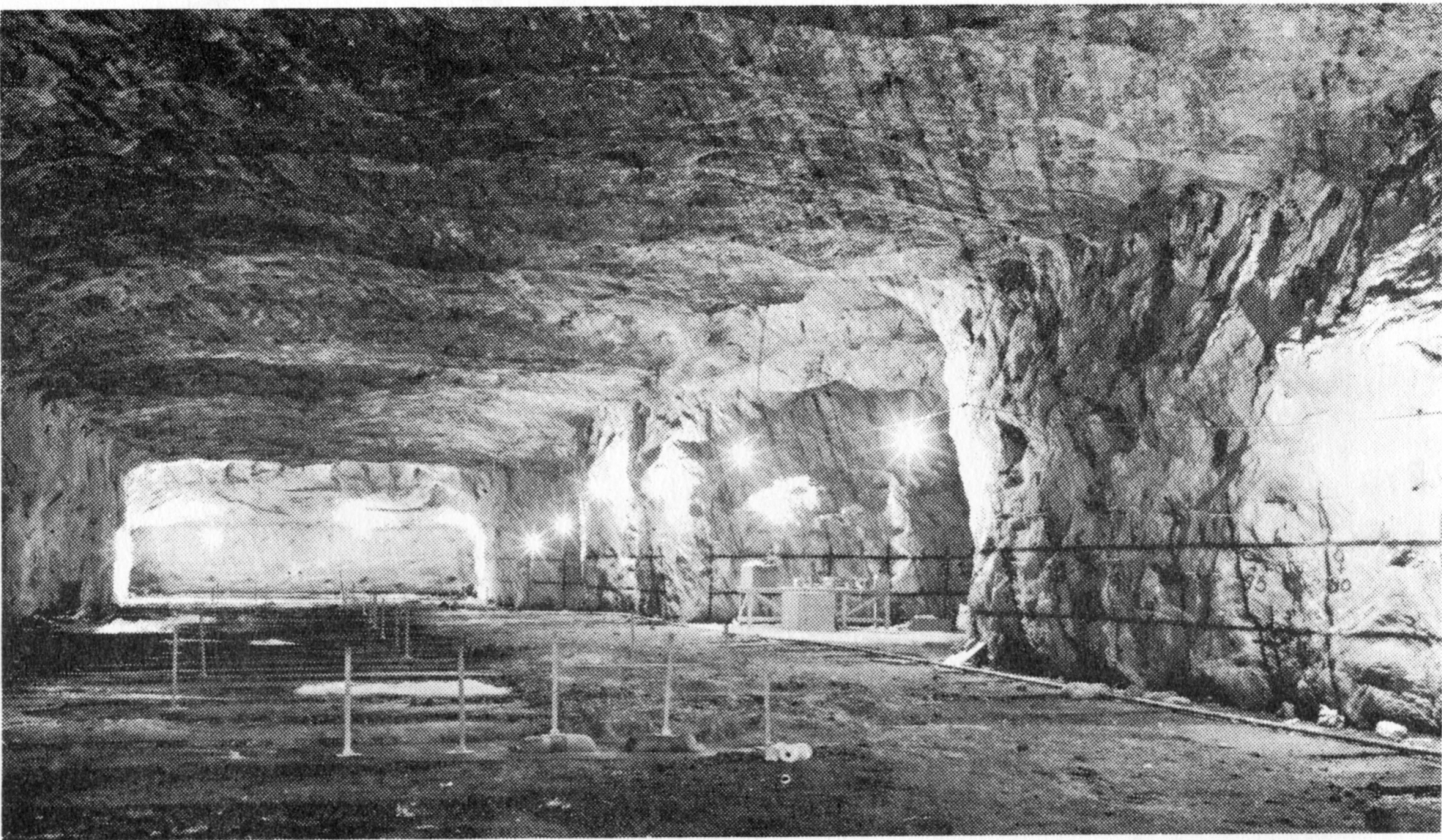
- governance and safety culture
- the need for error correction and reversibility of decisions



HANFORD SITE CROSS SECTION SCHEMATIC SHOWING WASTE DISPOSAL FACILITIES





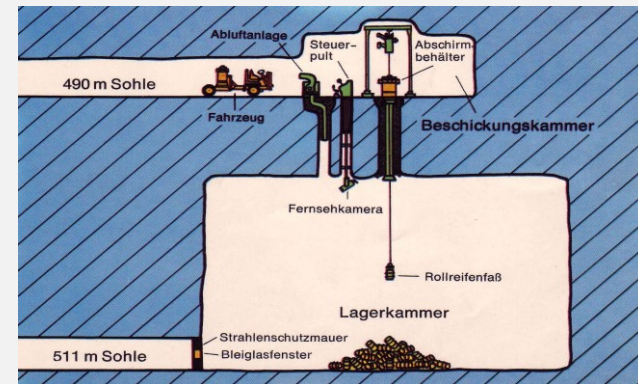


Interior View of Carey Salt Mine

Project Salt Vault Lyons Kansas (1965 – 1968 / 1970 - 1972)



*Test on spent fuel assemblies (Walker 2006/2007)
Project Salt Vault, as the Lyons study was called, commenced
in the fall of 1965 and lasted until January 1968. Here
researchers conduct tests on fuel assemblies buried in a salt*



Section through Asse Mine, the upper 511m-level contains intermedian level waste, the lower chambers on the 750 m-level low-level waste (both contaminated with transuranic substances)

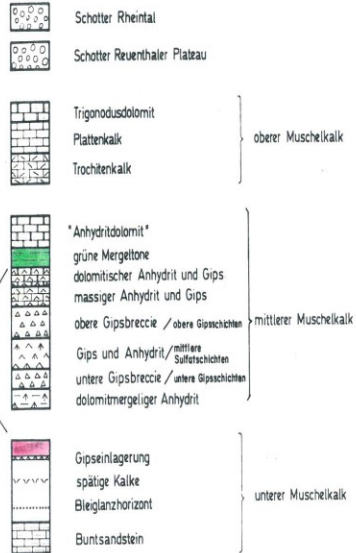


NNW

1:2000

1:2000

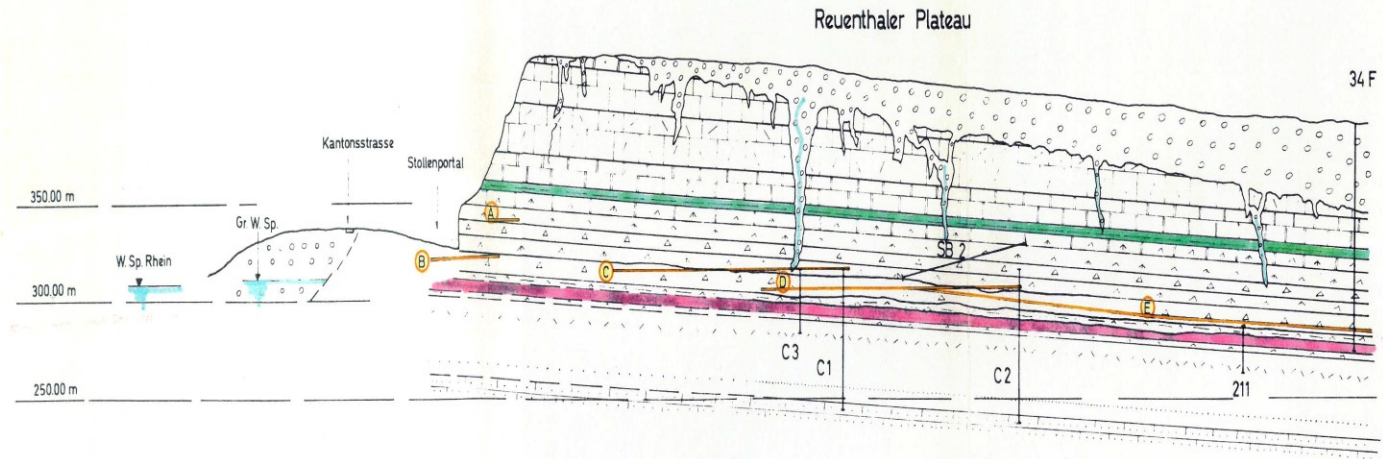
Legende:



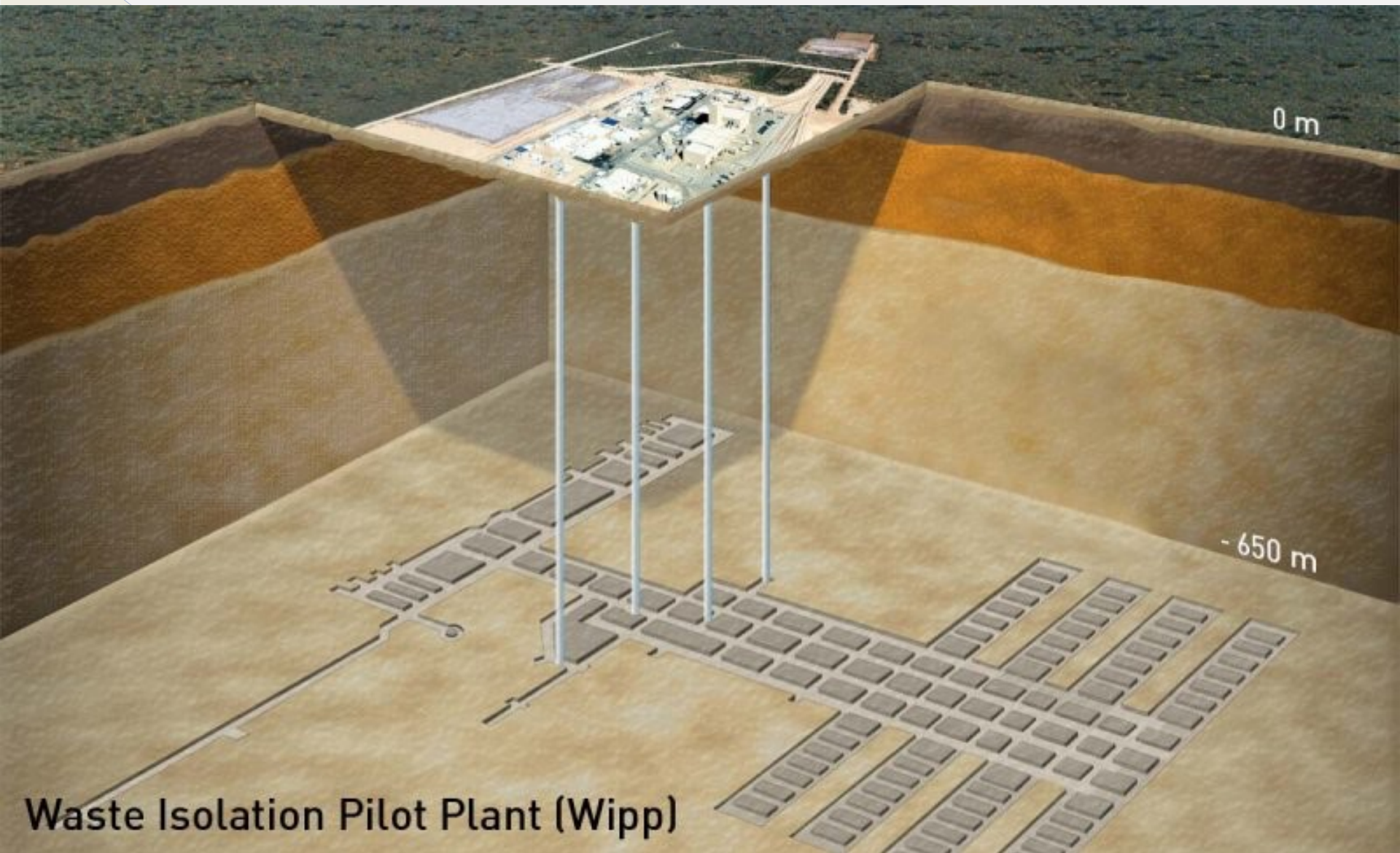
A, B, C, D, E

Abbausohlen

Bohrungen im Streichen der Schichten auf Profilaxe projiziert



Geological section through the Muschelkalk of northwestern Switzerland at the location of the gypsum-mine of Felsenau, Full-Reuenthal, Argovia (caverns as yellow lines A to F between green and violet horizon). The karst extends into the mining galleries.



Waste Isolation Pilot Plant (Wipp)

Clothings

Tools

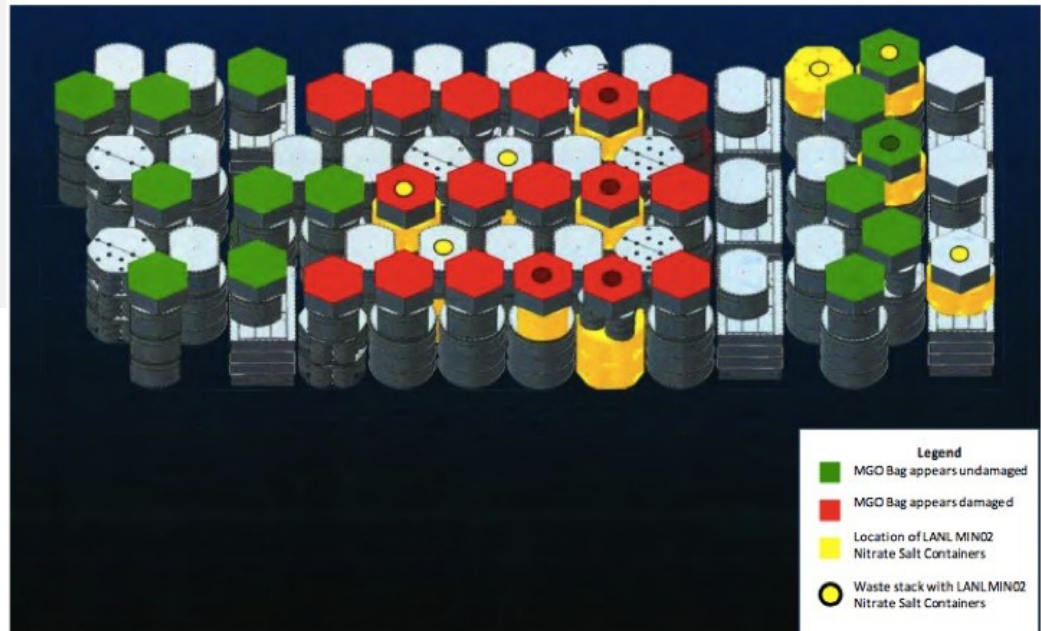
Equipment

Sludges

Soils

Other materials

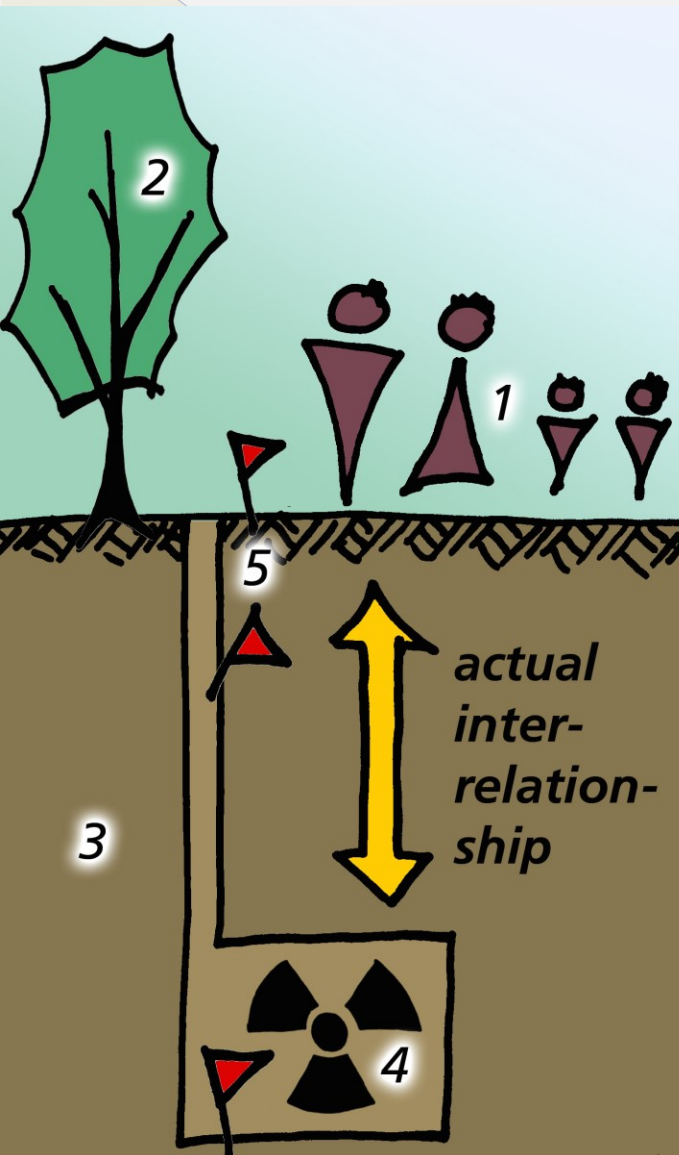




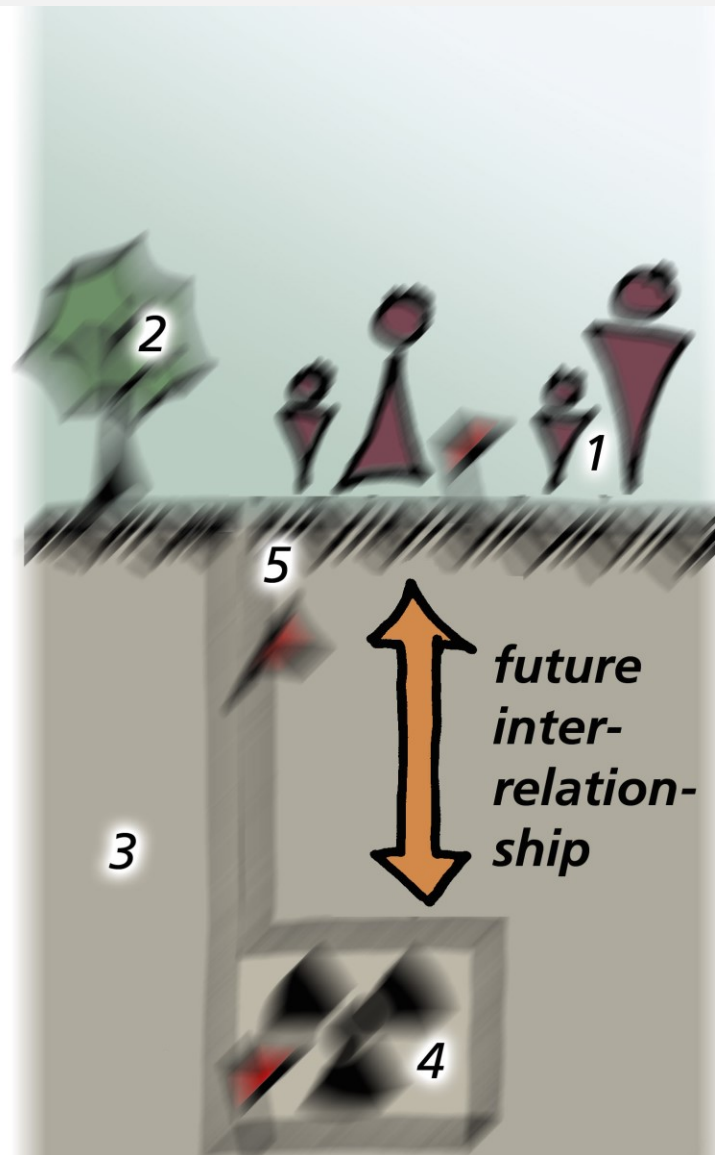
Position of containers from the production line LA-MIN02-V.001 with TRU-containing nitrate salts (yellow circles) and stiffened cardboard bags with magnesium oxide (bags affected in red, bags not affected in green), according to Figure 2-4 of the Department of Energy (DOE) report, investigation phase 2, dated April 2015



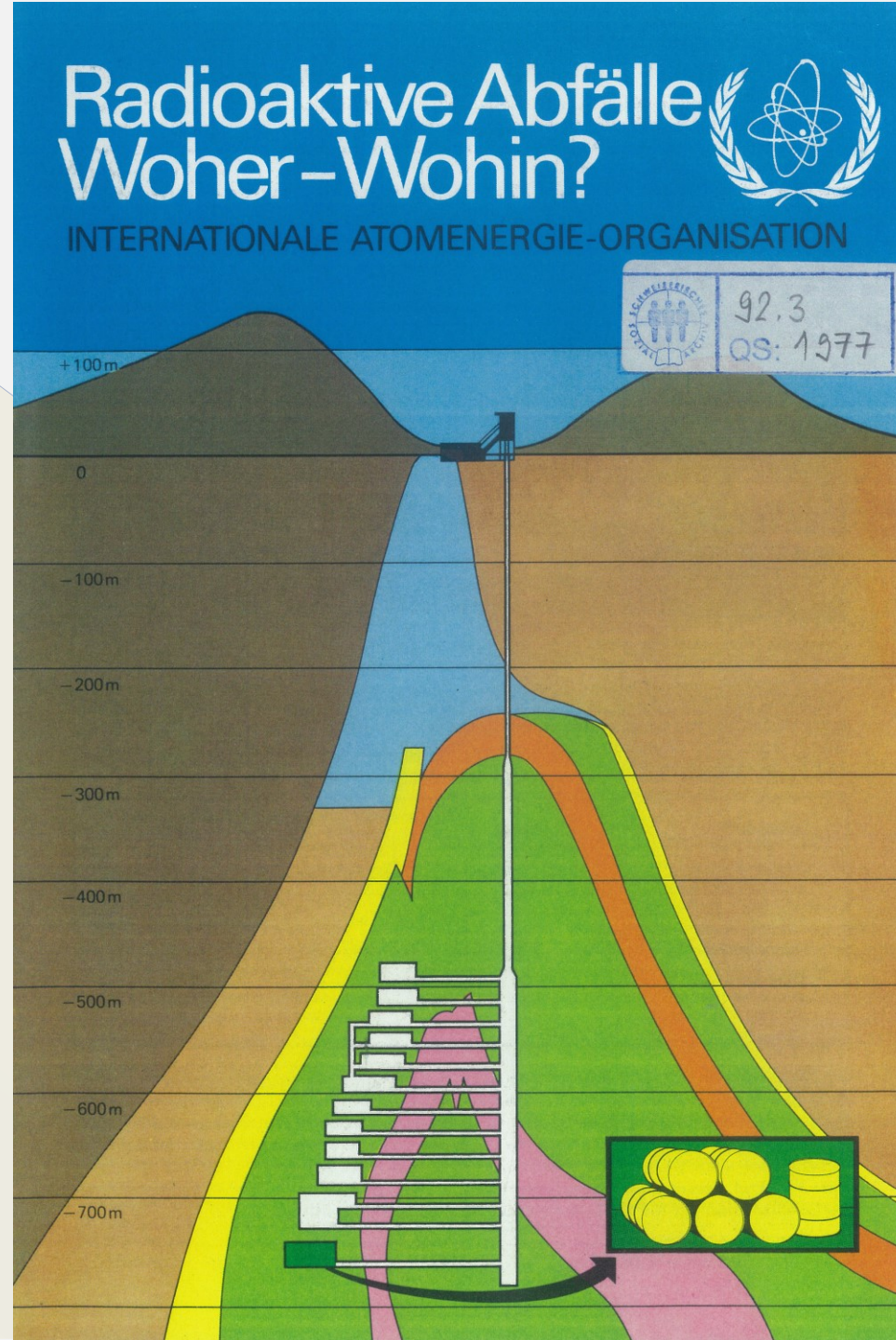
WIPP: Roof collapse 2016



> 10.000 years



IAEA 1977:
Model Asse



Area	Repository	Asse	DMS	Stocamine	WIPP
Legal context					
• Legal Situation		Amalgam of laws, grey areas in application	Legal basis available	Legal basis available	Legal basis available
• site conformity		Originally yes, today no longer	Not legally compliant	Originally yes, today questionable	Yes, with reservations
• Conformity of operation		Not legally compliant	Not legally compliant	Not legally compliant	Not legally compliant
• Reversibility		No requirement	For interim storage facilities as a condition in the operating permit. Not respected	For interim storage facilities as a condition in the operating permit. Not respected	Provided à priori
Location, Geology					
• Choice of location		No site selection procedure	Site selection procedure overlooks exclusion criteria	No site selection procedure	Site selection procedure with shifts
• Host rock		rock salt, water-permeable in places	Reef limestone, permeable to water (karst)	rock salt, partly open along the old mine	rock salt, brine and gas inclusions
• Hydrogeology		Inflows for decades, slow flooding in progress	Inflows flow off again at the bottom of the mine	Inflows for decades, flooding in progress	Desert climate, de facto no flooding expected today
• Stability of the underground repository		No, strong convergences	Yes, but a lot of roof collapses	No, strong convergences	No, strong convergences
Waste and plant					
• Type of waste		Radioactive mixed waste	Chemo-toxic wastes, type residual landfill	Chemo-toxic waste, type UTD DK IV	TRU wastes (durable ATA)
• Conditioning		Partially, e.g. concrete shielding	Cement consolidation	Mostly not (waste loose in drums/big-bags)	Partly, in different containers
• Backfilling (inclusion)		No	Intended	No	No
• Recovery of waste		Required and foreseen	Is done (completely)	Restricted, in progress	Potentially possible
• Closures, shaft custody		After dismantling: planned	Mine filled with excavated material, no closure	Special closures provided, effect unknown	Special closures are required, effect unknown
Economic efficiency					
• Cost factor		Central for selected disposal path and operation	Central for selected disposal path and operation	Central for selected disposal path and operation	Important for selected disposal path, central for operation
Structures and cultures					
• Operating structures		Not Adequate	Not Adequate	Not Adequate	No (more) adequate
• Supervision		Not Adequate	Not Adequate	Not Adequate	Available (EEG), then rationalized away and overstrained
• Safety culture		None or not implemented	None or not implemented	None or not implemented	Existing, not systematically implemented

An example of a comparative analysis

SAFETY REPORTS

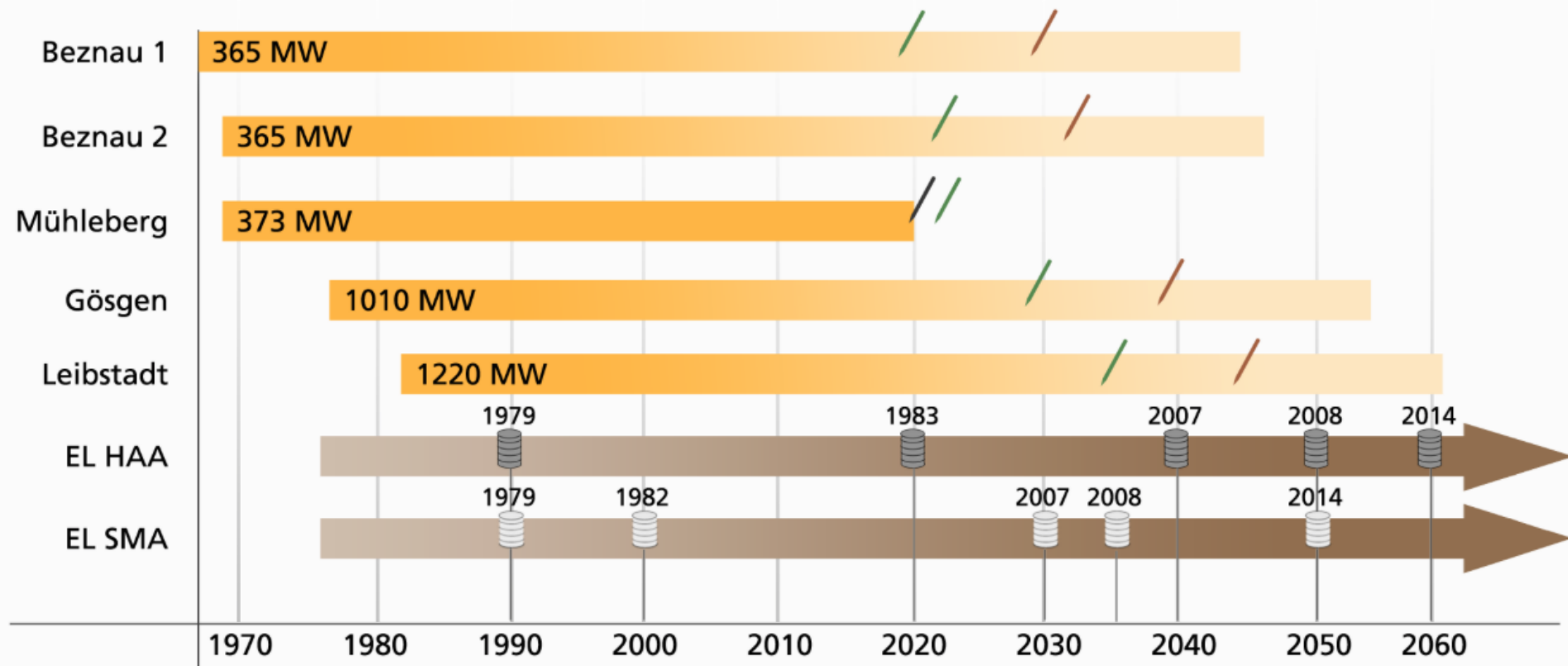
safety series

Safety Culture

A REPORT BY THE
INTERNATIONAL NUCLEAR SAFETY ADVISORY GROUP



INTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA, 1991



Abschaltprognose Bund



Abschaltprognose Betreiber



Verbindliches Abschaltdatum



Inbetriebnahme der Endlager mit Jahr der Prognose

EL Endlager

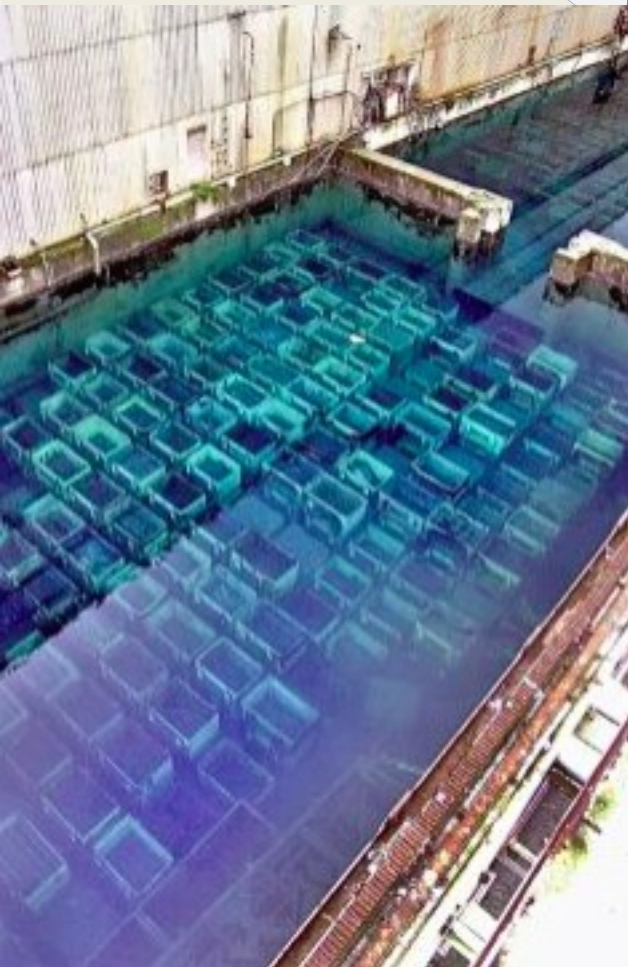
HAA Hochaktive Abfälle

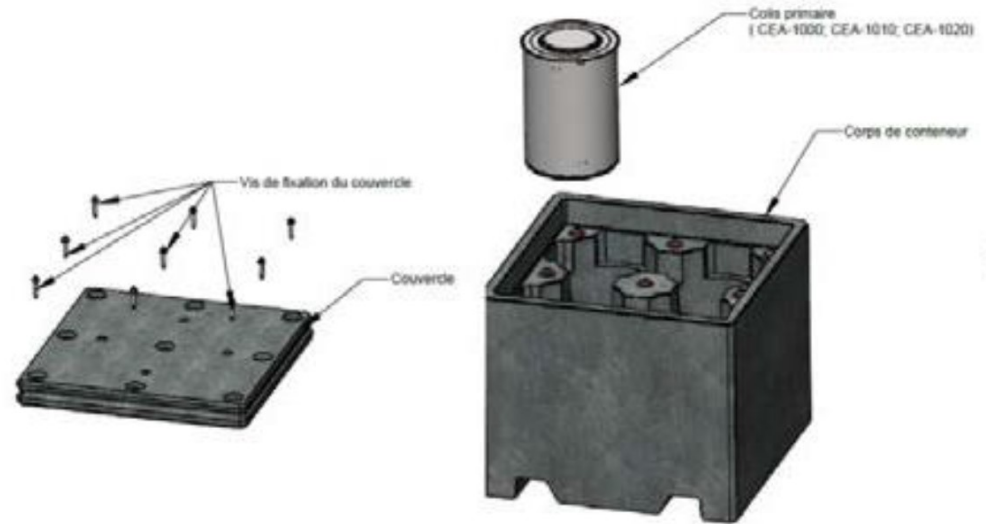
SMA Schwach- & mittelaktive Abfälle



Interim storage facility ZWILAG for HLW and LLW/ILW







Colis CS4

French CS4 package made of polypropylene fibre-reinforced concrete for 4 drums of bituminous waste per container



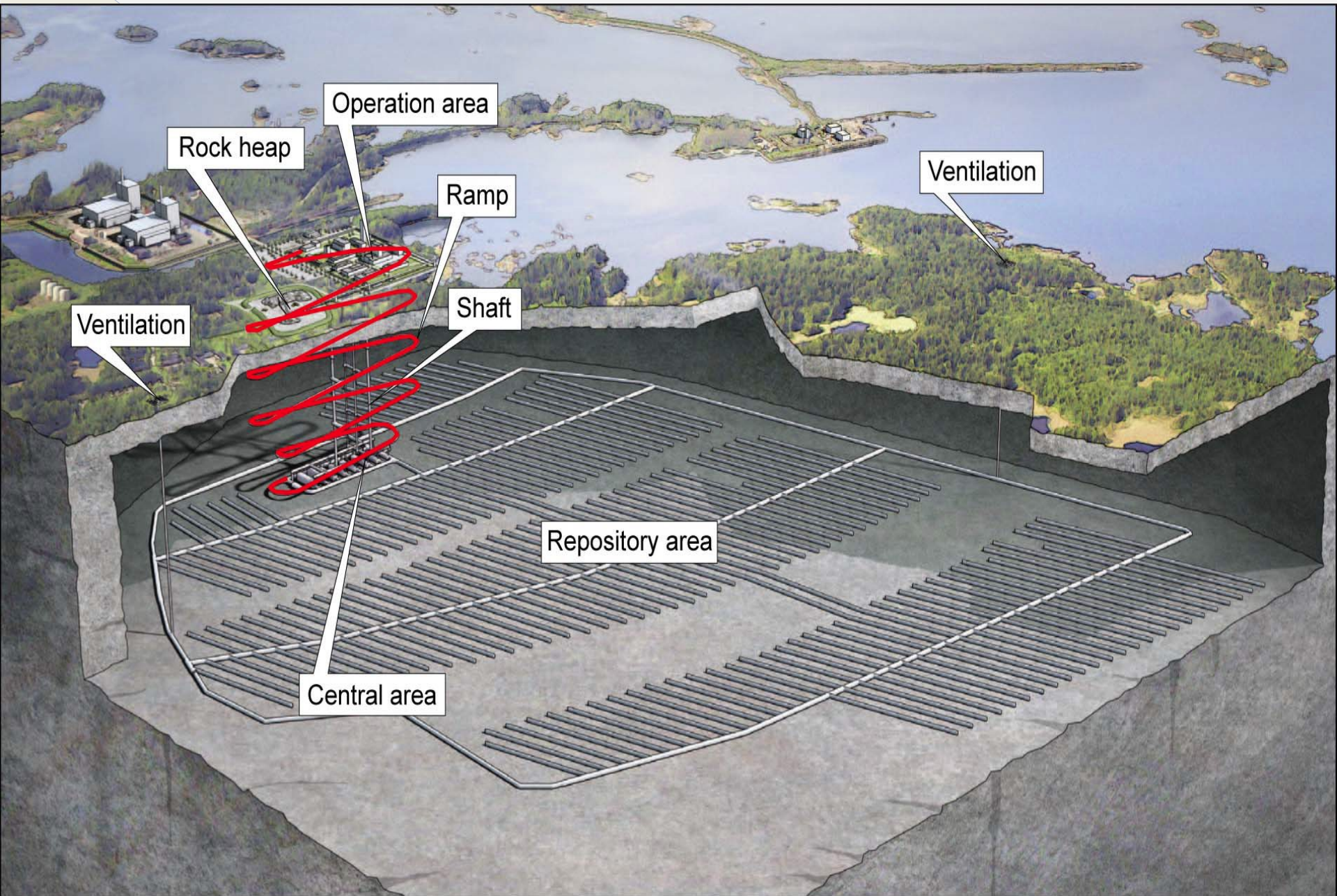
LLW/LIW-storage containers

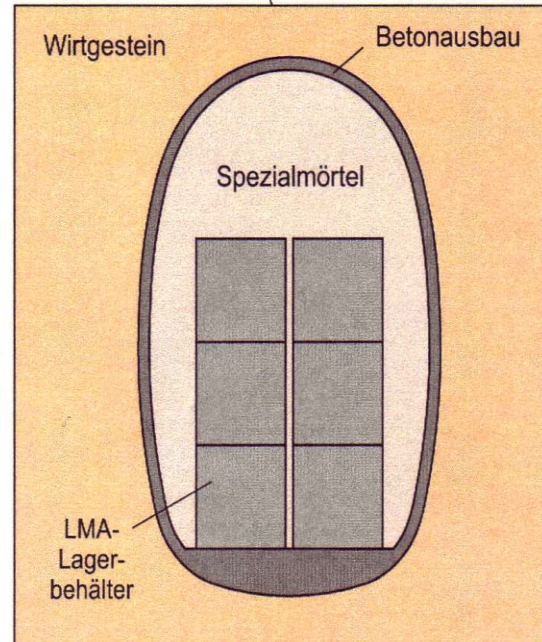
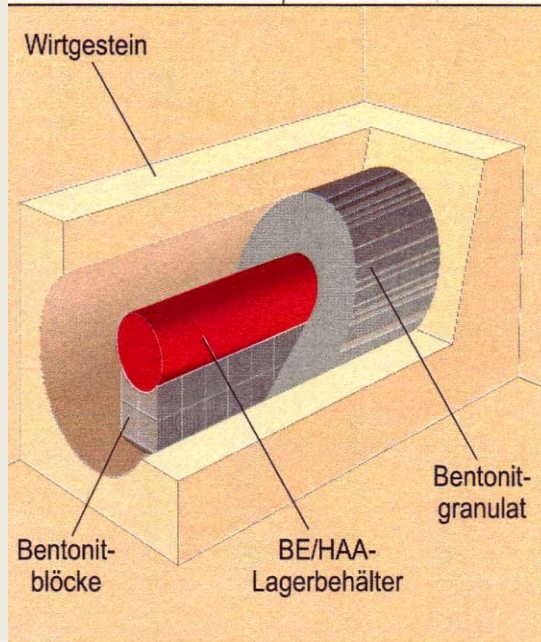
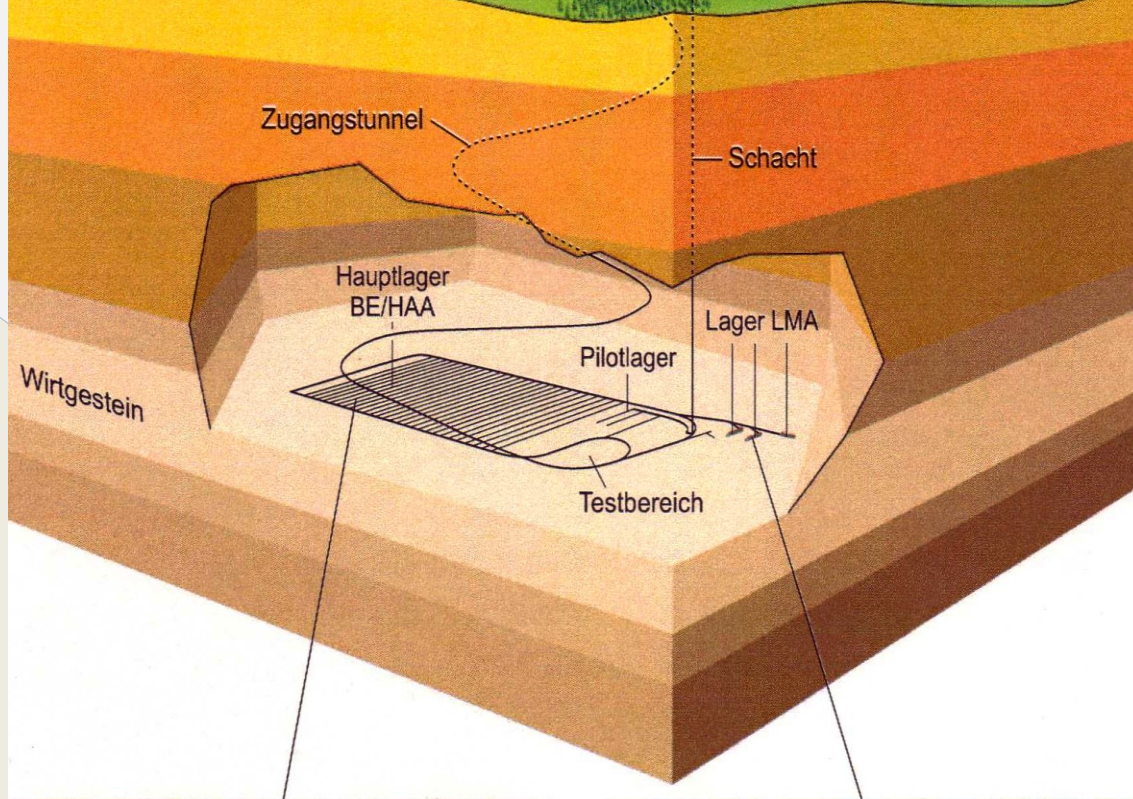
Top left: Nodular cast iron container of the company GNS for radioactive waste from water treatment plants of nuclear facilities, according to GNS

Top right: mosaic container of cast iron with nodular graphite of the company Gesellschaft für Nuklear-Behälter GNS

Bottom: Various bins and containers of Swiss waste management companies (Nagra 2014)

Exterior left: Steel container for vitrified HLW from reprocessing, center left: Cast steel container 1.3 m³ (Mosaic-II), center right: 1.2 m³ (concrete container), right outside: Storage container LC-86H filled with 200l steel drums





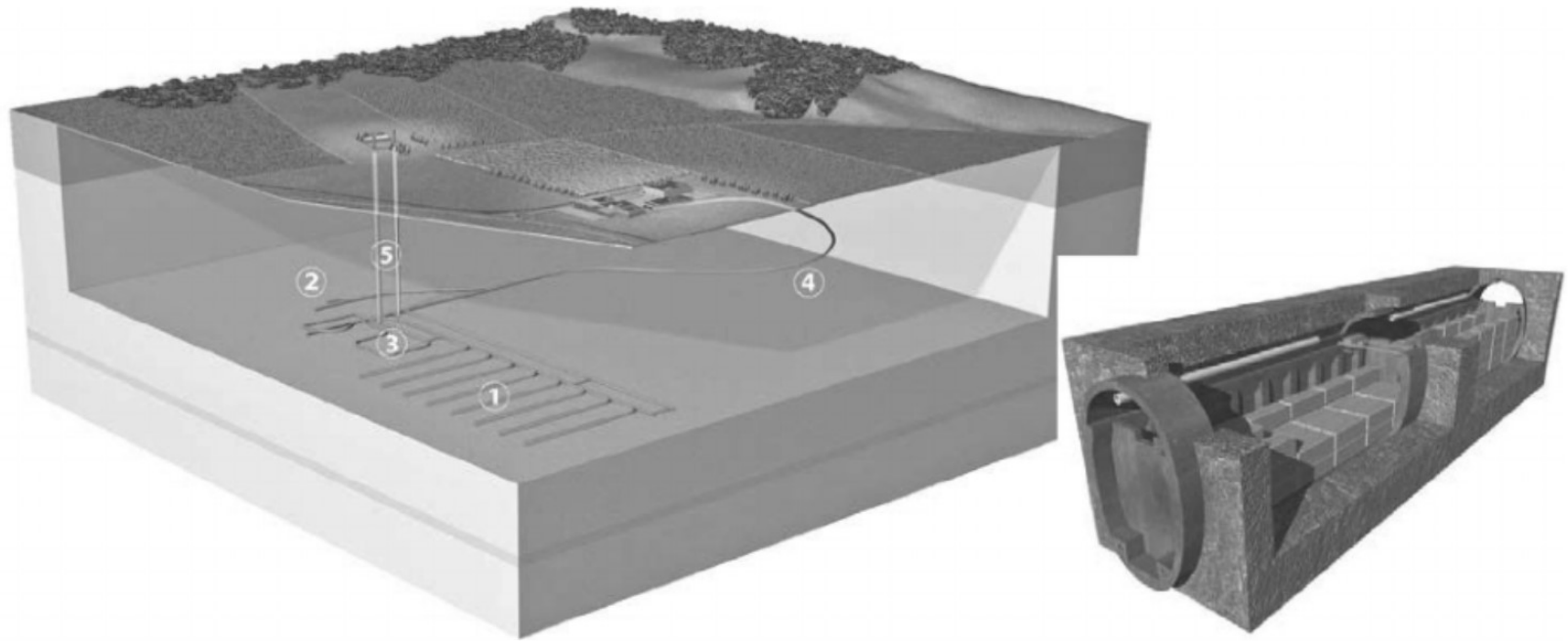
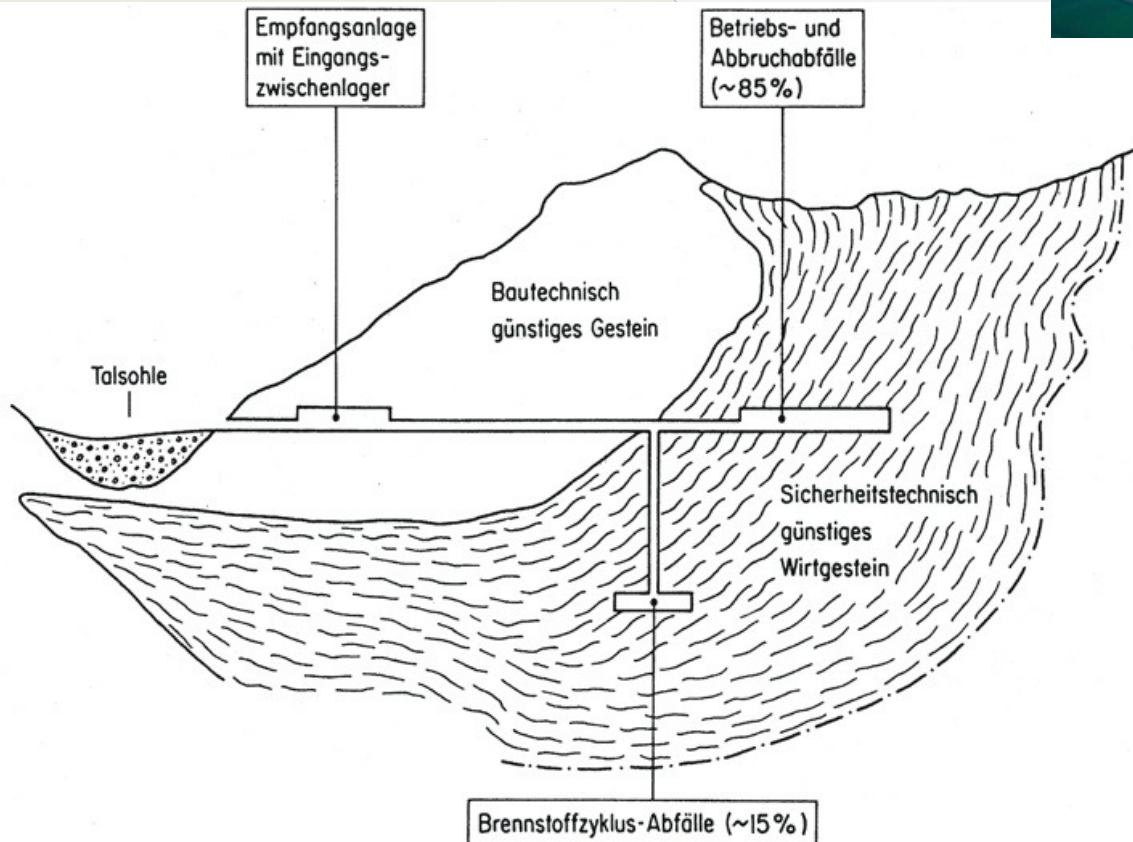


Fig. 4. Schematic of the L/ILW repository showing the main elements of the underground facilities and the disposal concept for low and intermediate level waste. 1-Low and intermediate level waste repository; 2-Pilot repository; 3-Test area (rock laboratory); 4-Access Tunnel; 5-Ventilation and construction shafts.

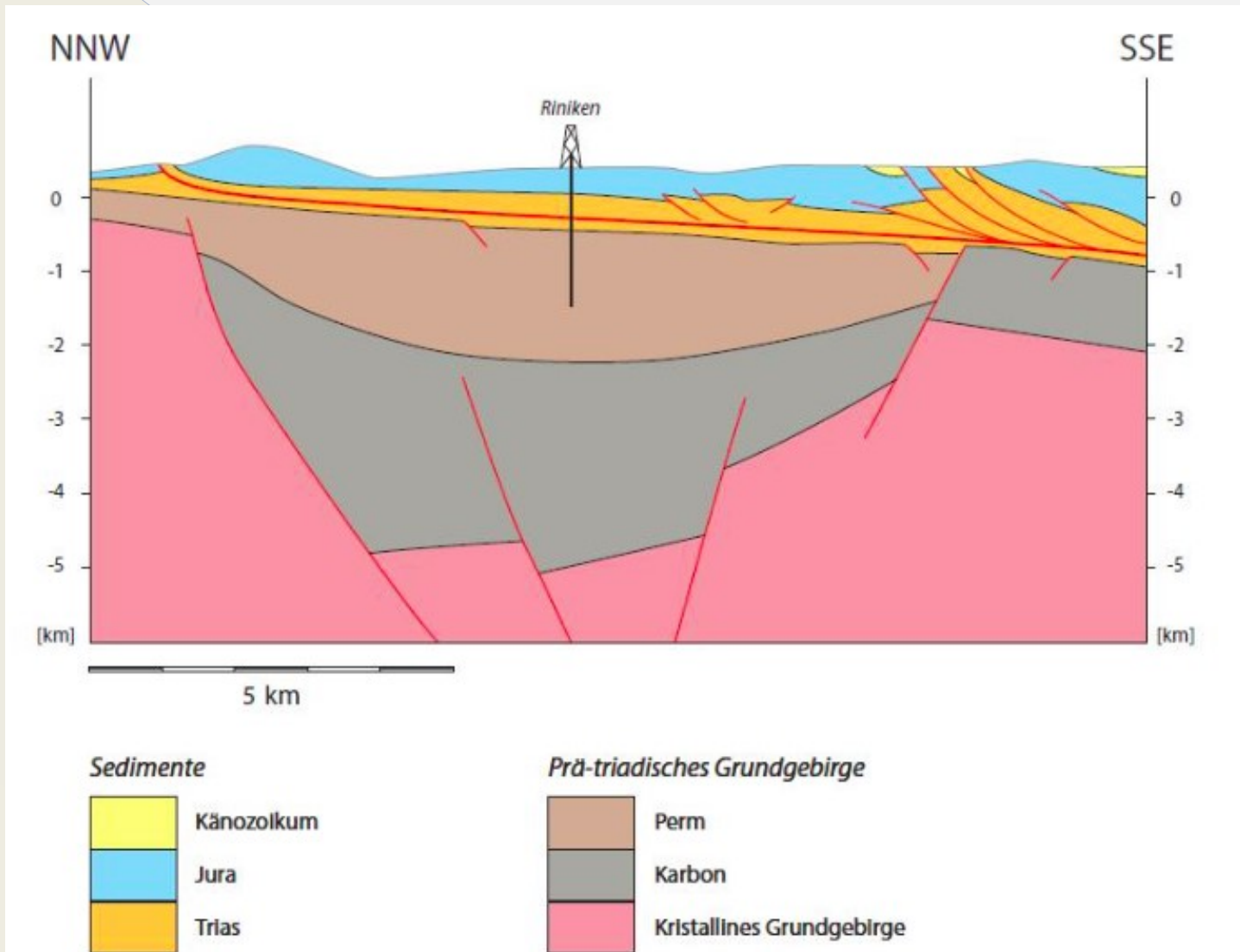
Development in LILW-Program

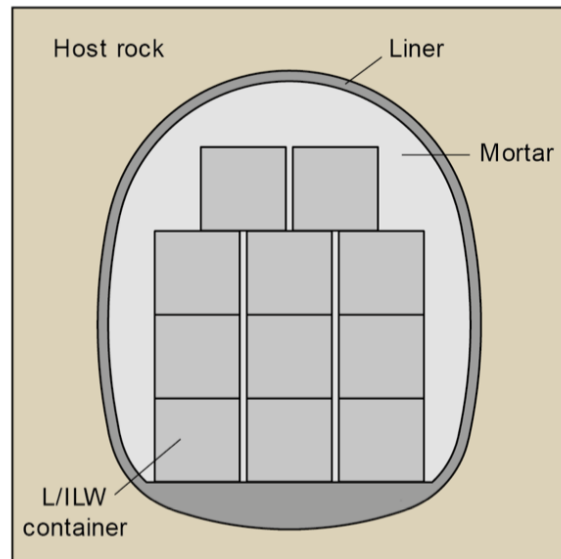
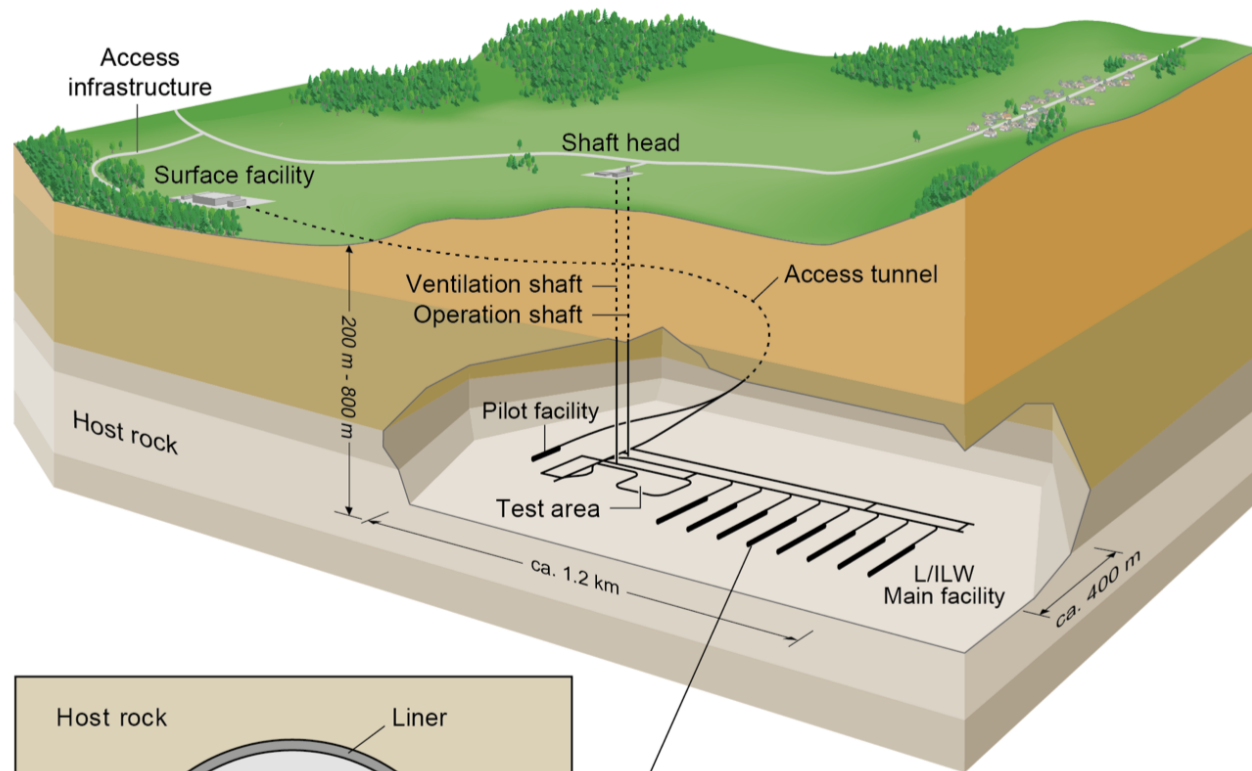
crisis of 2002: Wellenberg-project for LILW-repository failed, popular vote and rejection of the project

Restart of the site selection program (sectoral plan) after 2008



Deep through carved in the crystalline basement
permo-carboniferous rocks were not suitable for repository areas

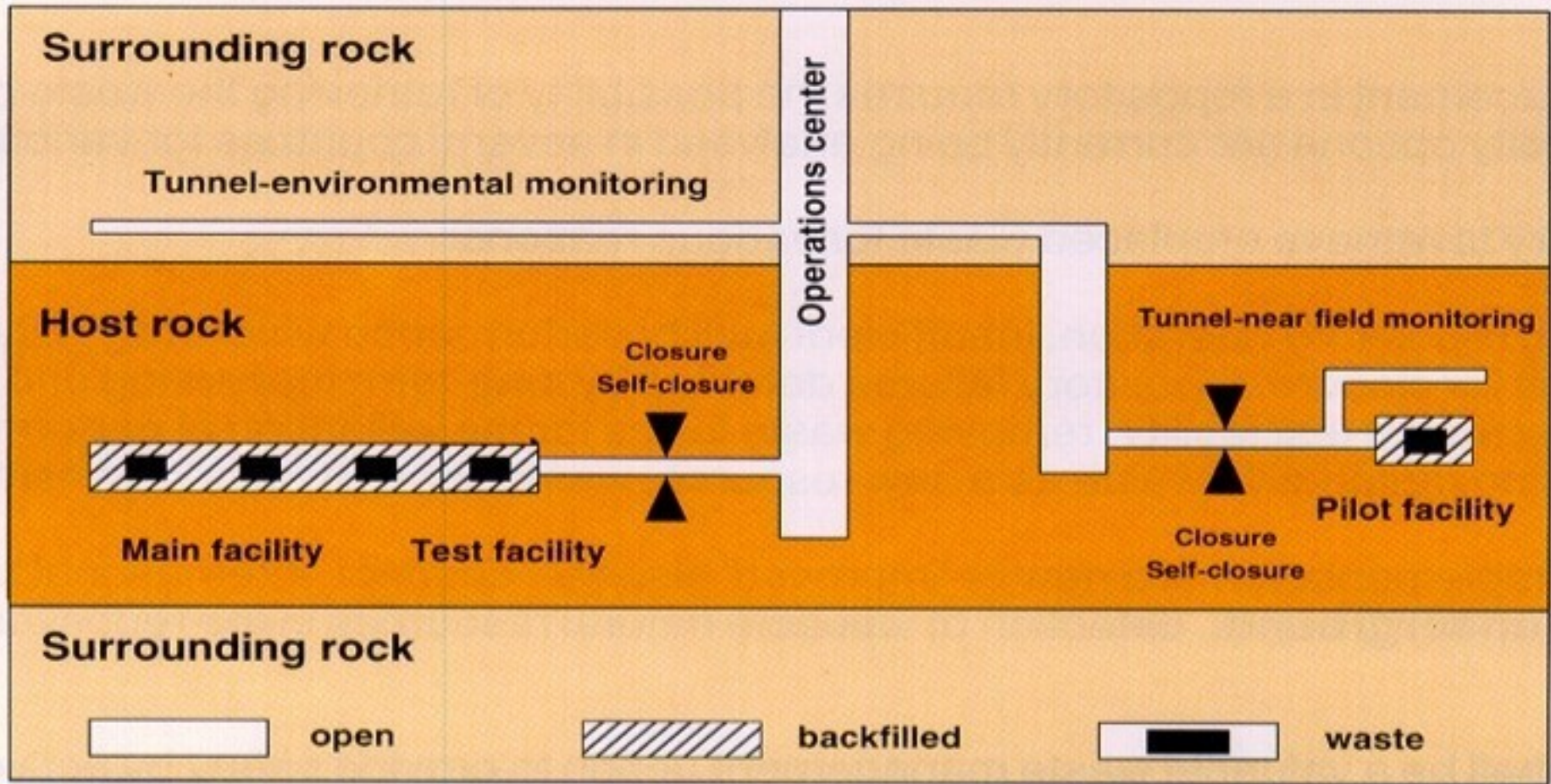




Emplacement cavern for L/ILW

Fig. 2-1: Conceptual outline of the deep geological repository for L/ILW (Nagra 2016).

Conventional repository, with fundamental innovations EKRA-Concept



Excavated Cross Section: 123.6 m²
Outer Circumference: 41.3 m

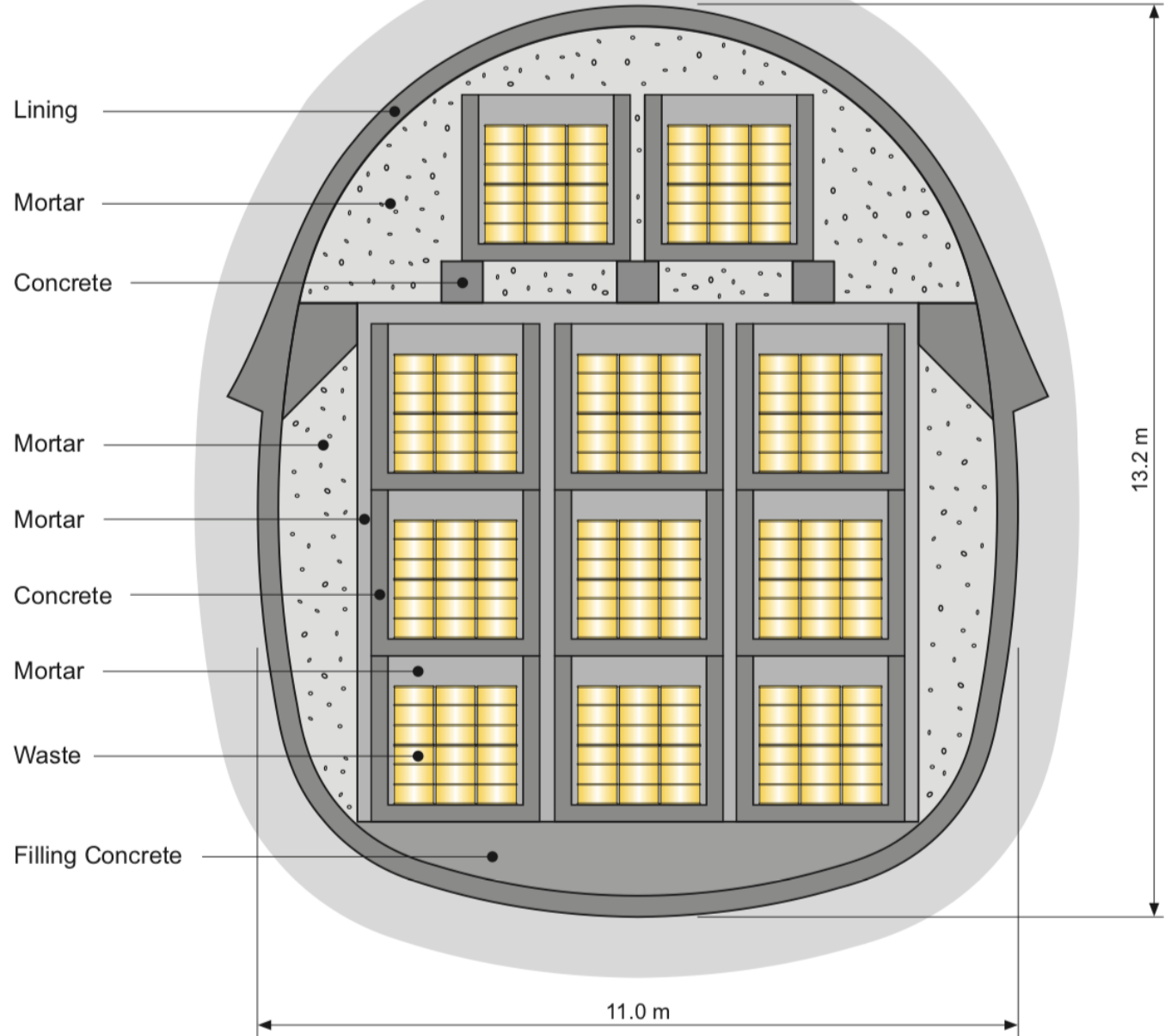


Fig. 2-3: Planned emplacement cavern for L/ILW waste (after Leupin et al. 2016).



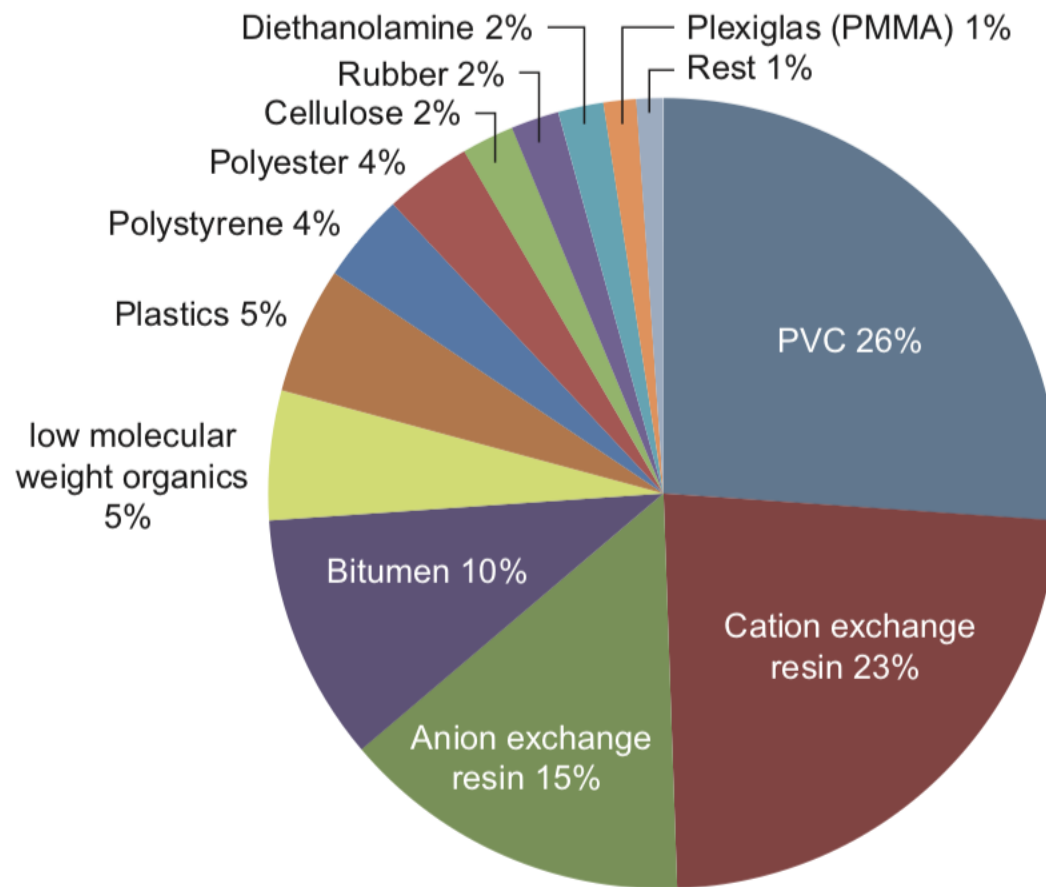


Fig. 2-5: Percentages of various organic waste components in a Swiss L/ILW repository based on Nagra (2014c).

Sources			Sinks		
Material	Process	Product	Sinks for H_2	Sinks for CH_4	Sinks for H_2S and CO_2
Steel	Anaerobic corrosion	$Fe^{2+} + H_2$	Diagram illustrating sinks for H_2 and SO_4^{2-}. H_2 is converted to CH_4 and H_2S. SO_4^{2-} is converted to H_2S. H_2S and CO_2 are then converted to CH_4.	Diagram illustrating sinks for CH_4 and SO_4^{2-}. CH_4 is converted to $CO_2 + H_2S$. SO_4^{2-} is converted to $CO_2 + H_2S$.	Diagram illustrating sinks for H_2S and CO_2. Fe^{2+} and H_2S are converted to FeS. CO_2 and $Ca(OH)_2$ are converted to $CaCO_3$.
Organic waste	Sulfate reducing degradation Methanogenic degradation	$CO_2 + H_2S$ $CO_2 + CH_4$			
Opalinus Clay	Dissolution of minerals (e.g. celestite)	SO_4^{2-}			
Cement	Cement degradation	$Ca(OH)_2$			

Fig. 3-2: Different gas sources and sinks.

The gas sources originate both from chemical and microbial reactions. Sinks in blue are microbial sinks, while sinks in green are chemical sinks.

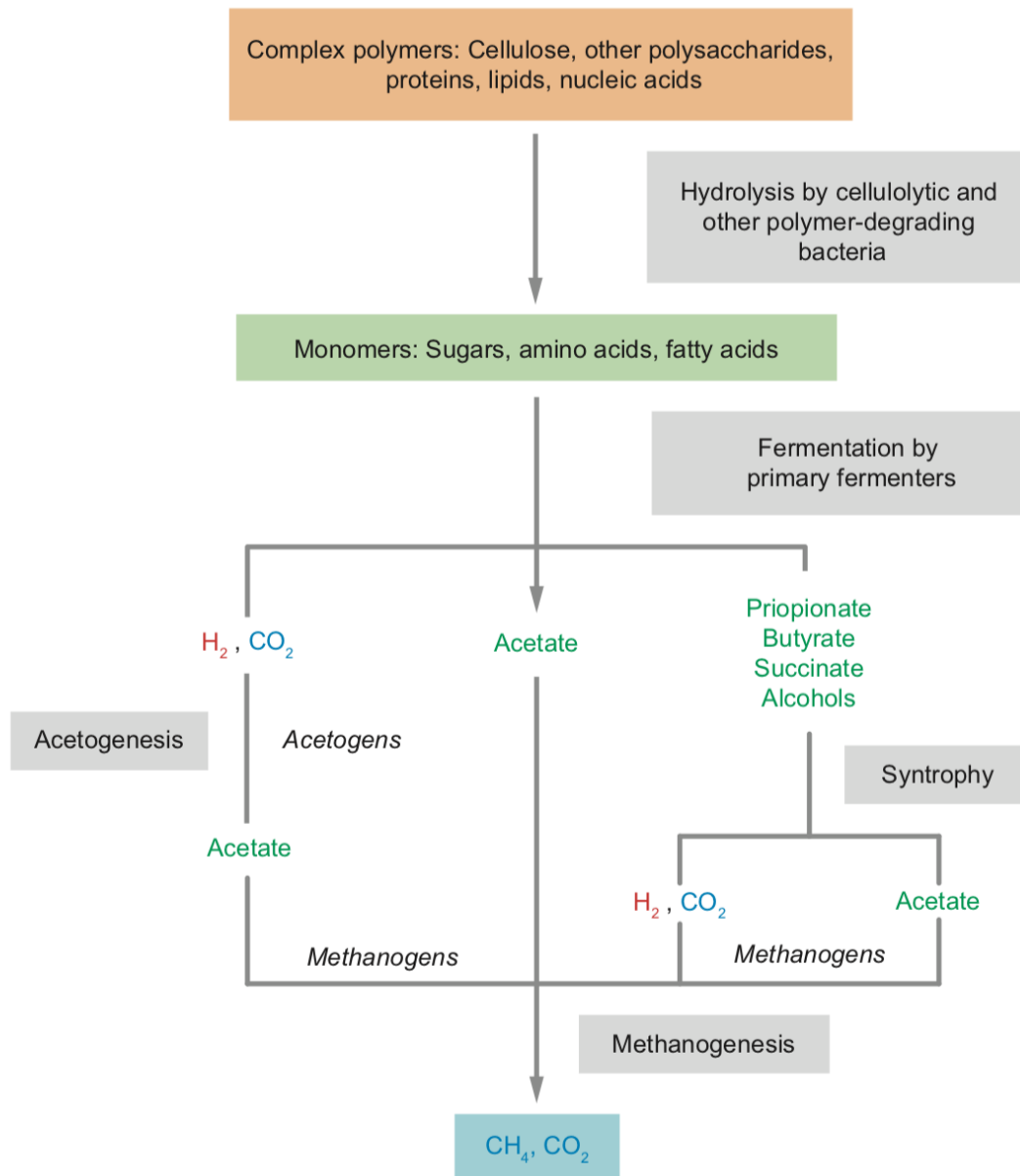


Fig. 3-3: Under anoxic conditions various groups of fermentative anaerobes cooperate in the conversion of complex organic materials to CH₄ and CO₂.

This pattern occurs in environments in which sulphate-reducing bacteria play only a minor role (adapted from Madigan et al. 2015).

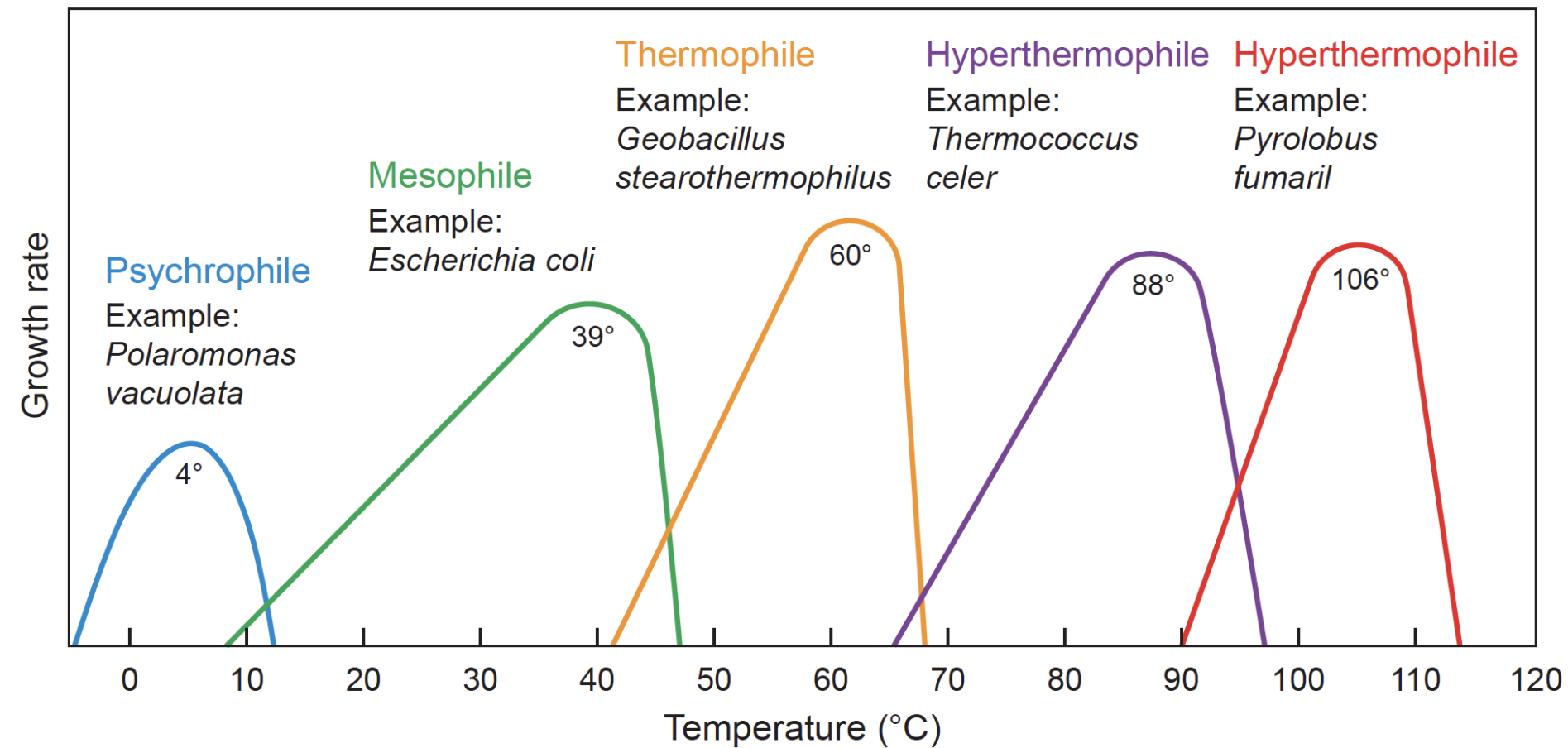


Fig. 2-8: Temperature and growth response in different temperature classes of micro-organisms.

The temperature optimum of each example organism is shown on the graph (after Madigan et al. 2015).

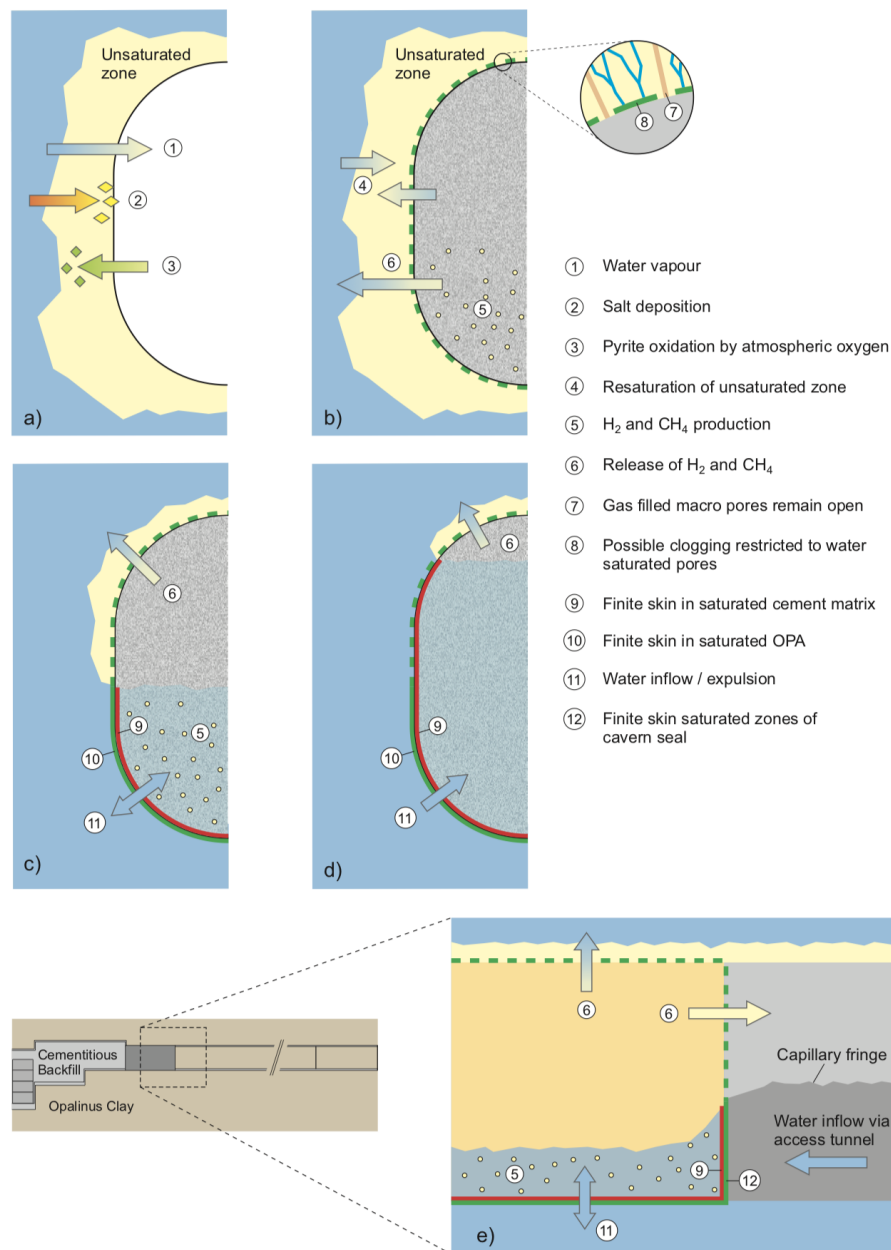
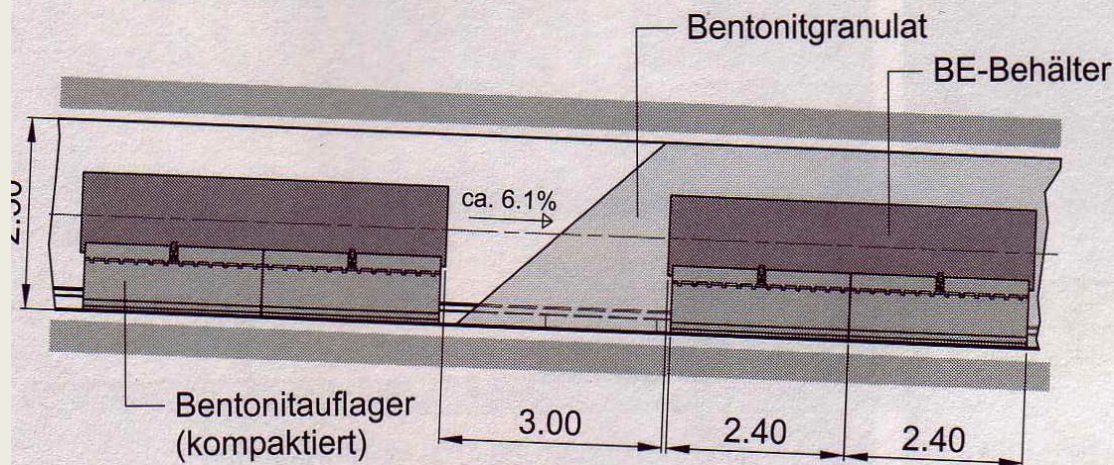
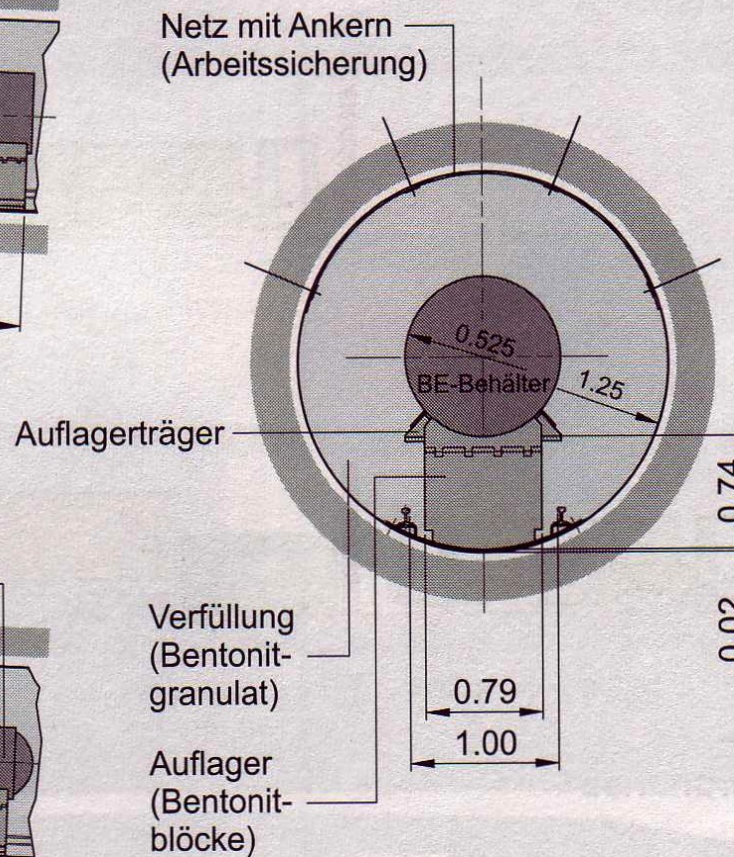


Fig. 2-7: Schematic sketch showing the evolution of an emplacement cavern near-field during the operational phase and after closure: a) Development of an unsaturated zone during the operational phase; b) – d) Mass transfer processes in the early time, mid time and late time after closure; e) Mass transfer processes around the emplacement cavern plug after closure (Nagra 2008).

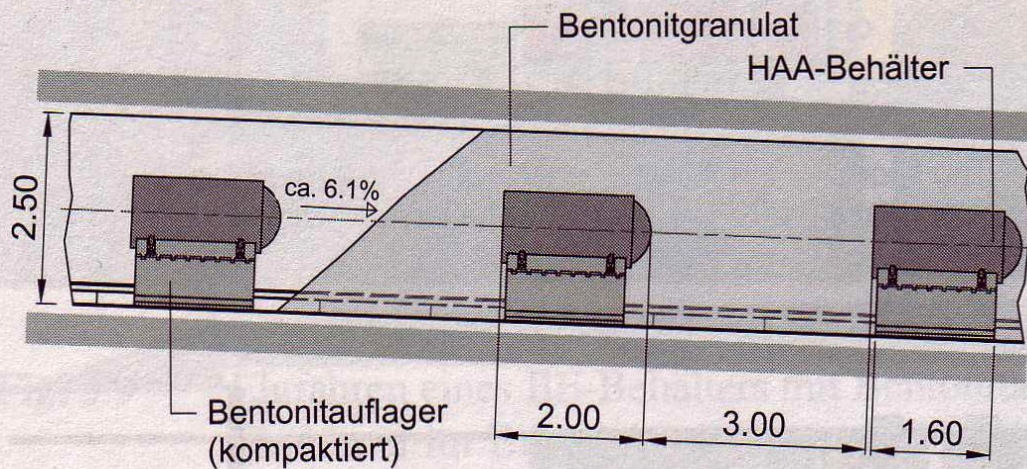
Längsschnitt BE

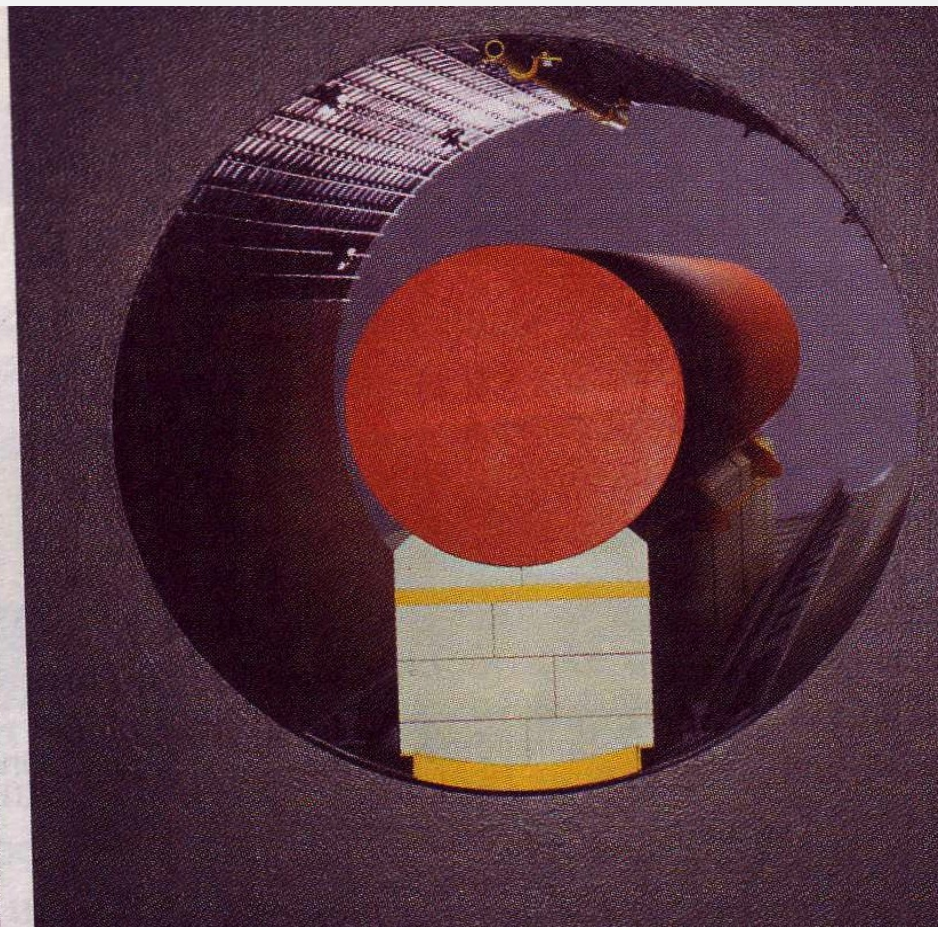
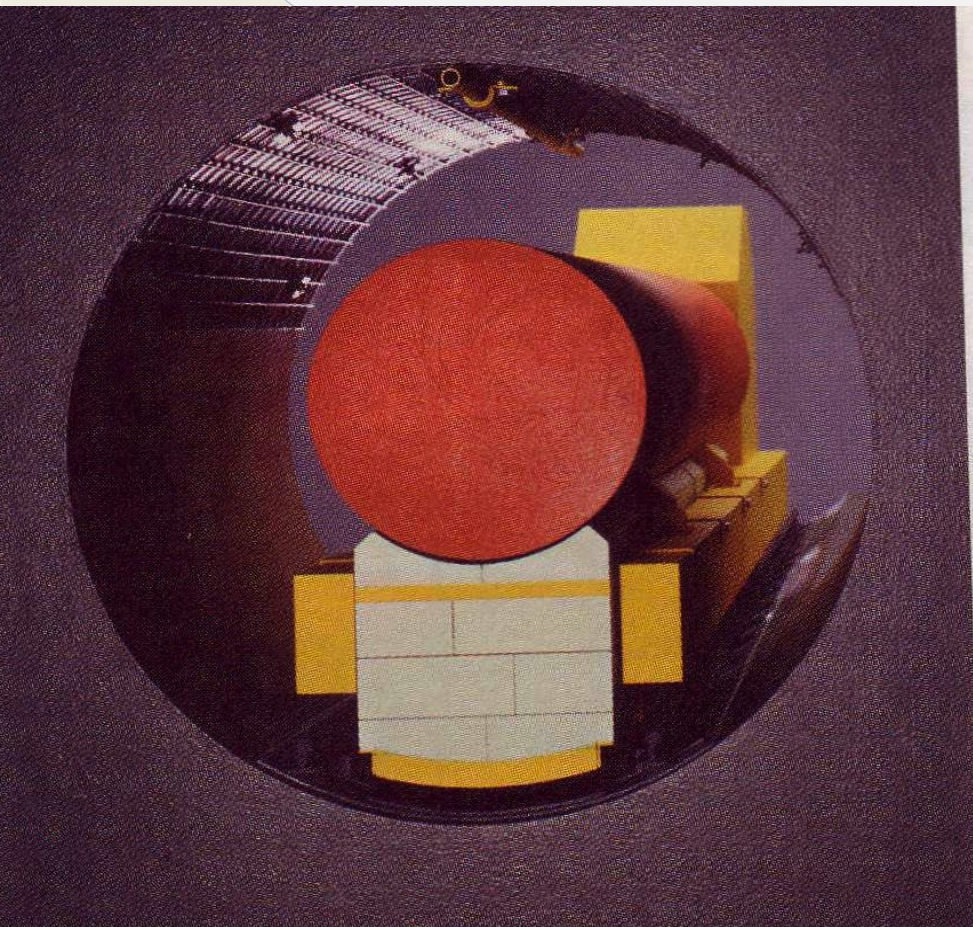


Querschnitt BE (verfüllt)

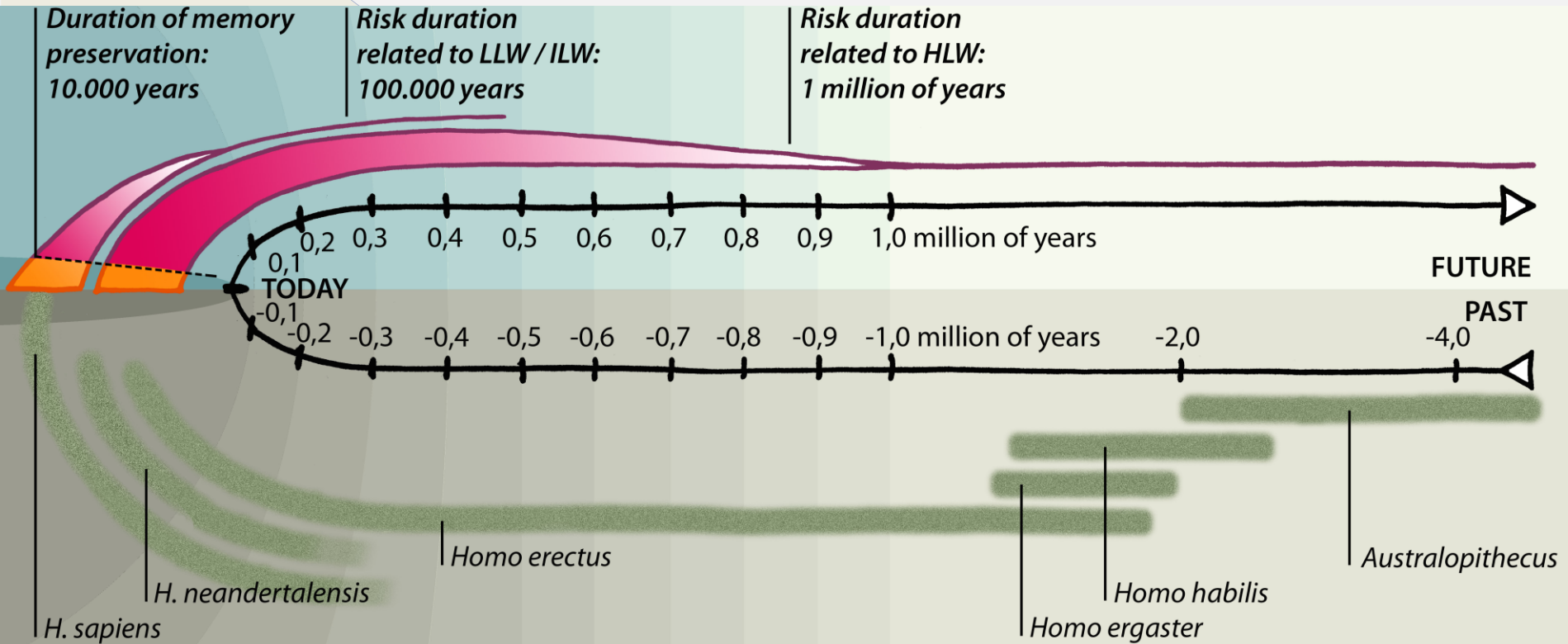


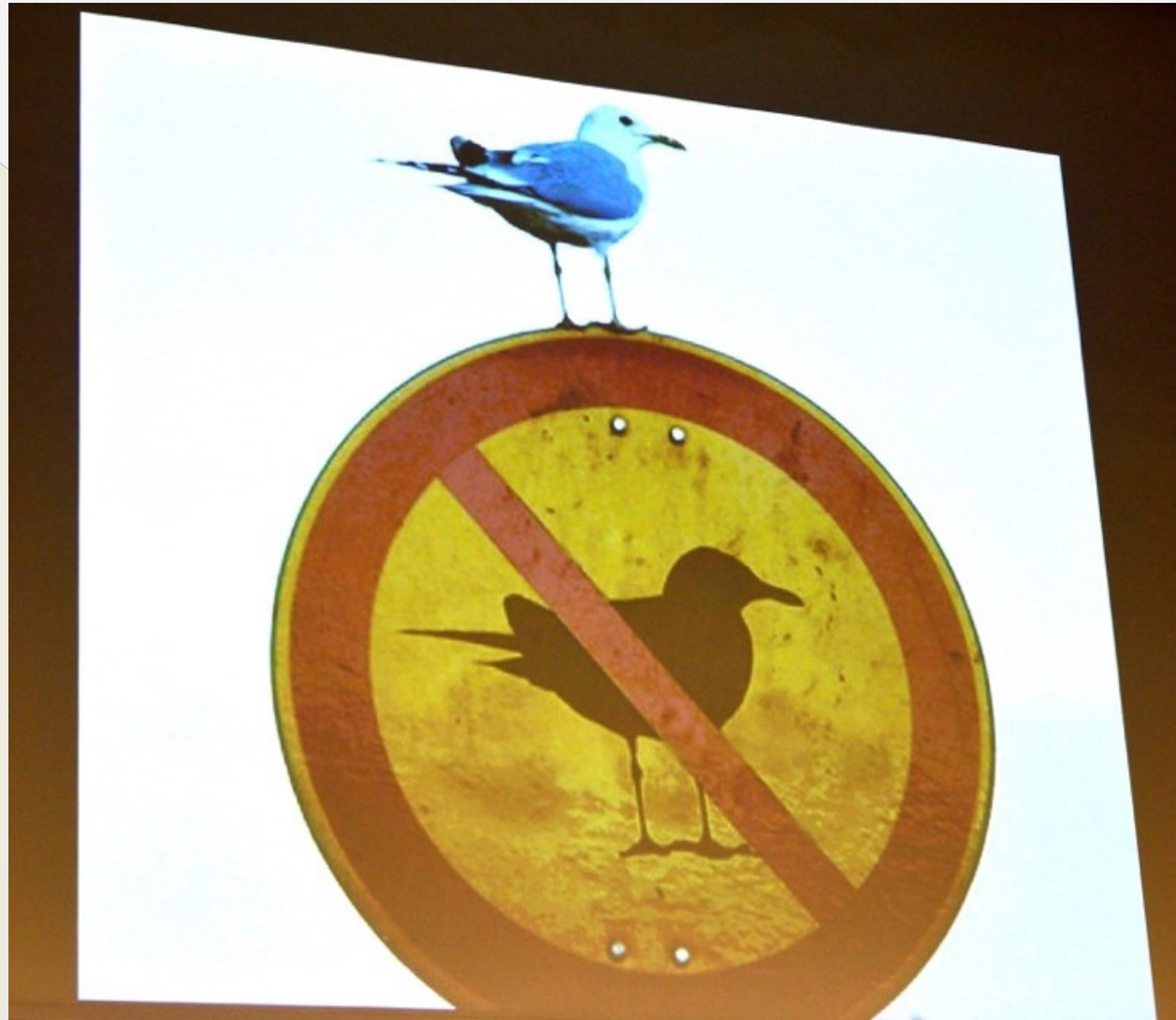
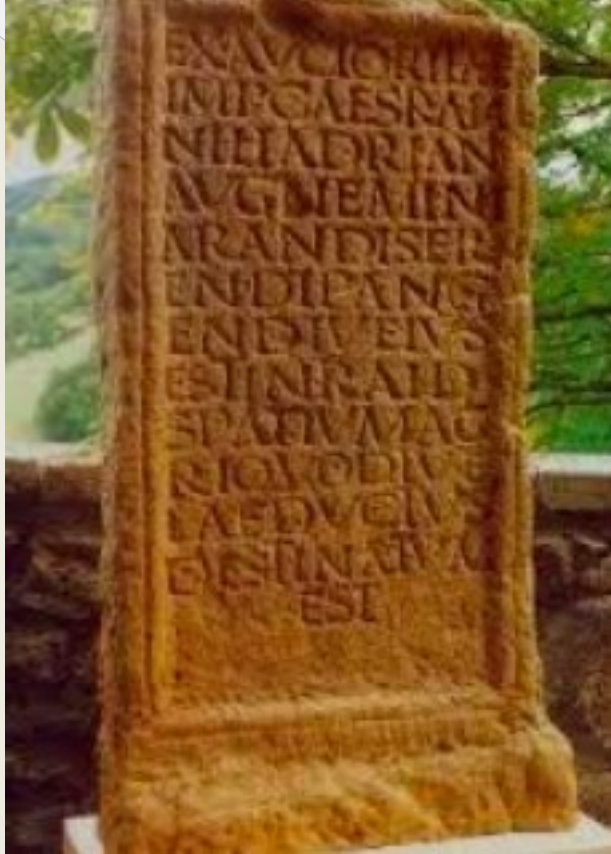
Längsschnitt HAA





Timescales







Abfälle in Tiefenlager (Einlagerung ab 2050)

Aktivität (Bq)

$2,96 \cdot 10^{18}$

$2,68 \cdot 10^{18}$

$2,37 \cdot 10^{18}$

$2,07 \cdot 10^{18}$

$1,78 \cdot 10^{18}$

$1,48 \cdot 10^{18}$

$1,18 \cdot 10^{18}$

$0,89 \cdot 10^{18}$

$0,59 \cdot 10^{18}$

$0,30 \cdot 10^{18}$

2050

+100 Jahre

+200 Jahre

+300 Jahre

+1000 J.

+10

100%

11,1%

3,3%

2,2%

1,0%

0

Restaktivität HAA im Vergleich zum Einlagerungsbeginn

0,15%

0,017%

0,005%

0,003%

0,0015%

0

Zerfall des hochaktiven Abfalls
HAA

Radionuklide mit kurzer Halbwertszeit verursachen den Hauptanteil der Aktivität der HAA. Sie sind in den ersten 100 bis 200 Jahren für die hohe Strahlung verantwortlich. Diese nimmt aber rasch ab.

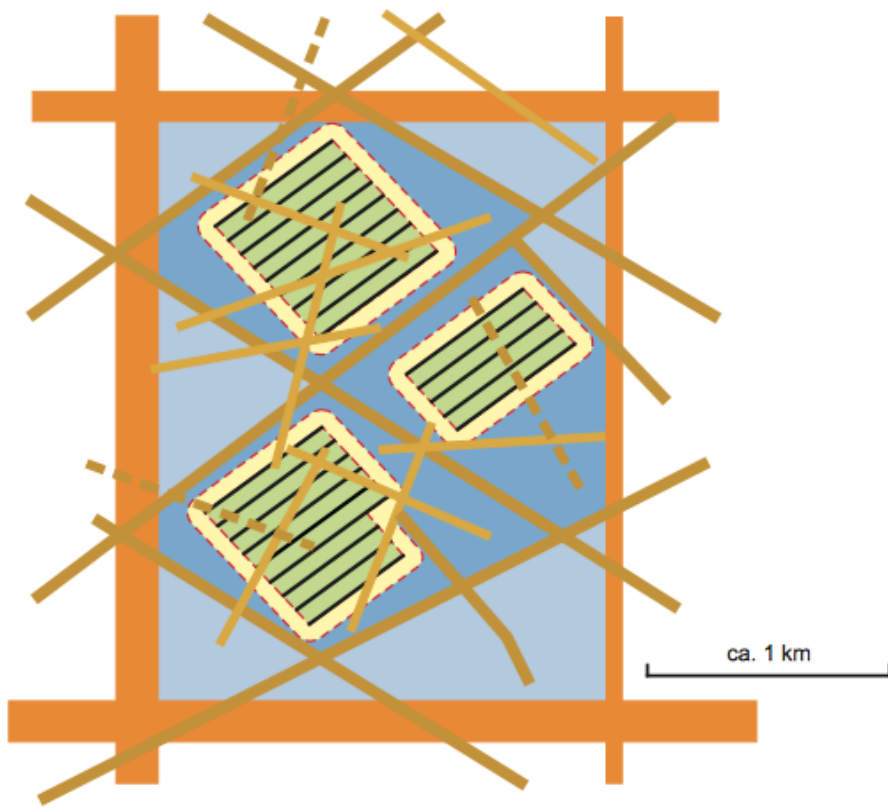
Die Anteile mit la-
strahlen schwach







Signatur	Beschreibung	Bedeutung
	gebietsbegrenzende geologische Elemente	gebietsbegrenzend
	anordnungsbestimmende geologische Elemente	bestimmt Anordnung der Lagerkammern
	einlagerungsbestimmende geologische Elemente	bestimmt Einlagerung innerhalb Lagerkammern
	kleinere geologische Elemente	in Sicherheitsanalyse berücksichtigt
	Lagerkammern	–
	Lagerkammerbereich	–
	Lagerfeld	–
	nutzbare Lagerzone	–
	nicht nutzbare Lagerzone	–



Anordnung Lager: Buser&Wildi 2015 (in Vorbereitung)