TU Clausthal

C|A|U Christian-Albrechts-Universität zu Kiel

ENTRIA

DISPOSAL OPTIONS FOR RADIOACTIVE RESIDUES: INTERDISCIPLINARY ANALYSES AND DEVELOPMENT OF EVALUATION PRINCIPLES

Radioactive Waste Disposal: Technical „Tour de Force“

Klaus-Jürgen Röhlig, Institute of Disposal Research

Salzburg, REFORM 18, August 26th 2013

This presentation …

- has been prepared on short notice in order to address some basic technical questions which arose during the meeting

- is based on the input for a „mock-up Bürgerforum“ which is planned for next week to be carried out by the universities of Kiel and Clausthal and to be hosted by Cusanuswerk

What is radioactive waste?

- A broad topic…

Source: BfS

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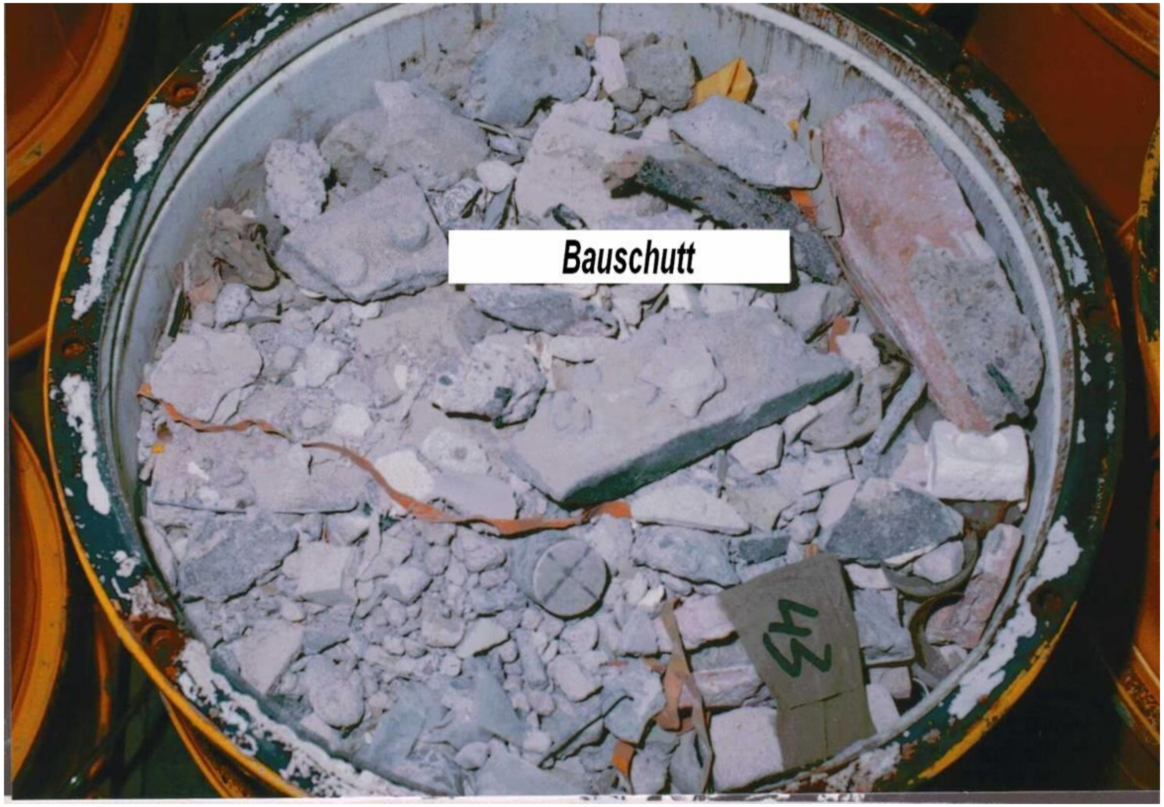


Source: BfS

What is radioactive waste?

- A broad topic…

Source: BfS

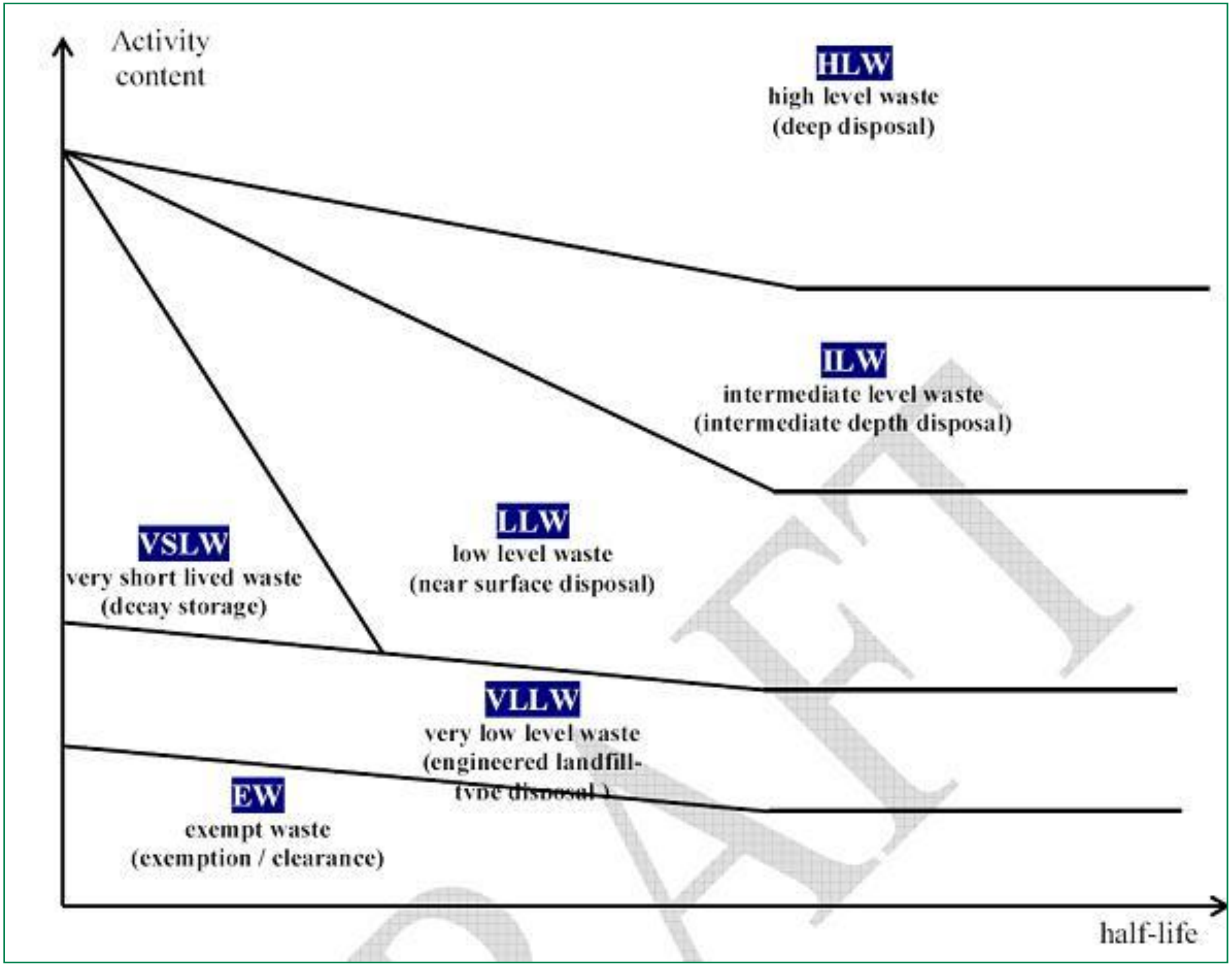
What is radioactive waste?

- a broad topic…

- different physical and chemical forms
  („from contaminated gloves to spent nuclear fuel element“)

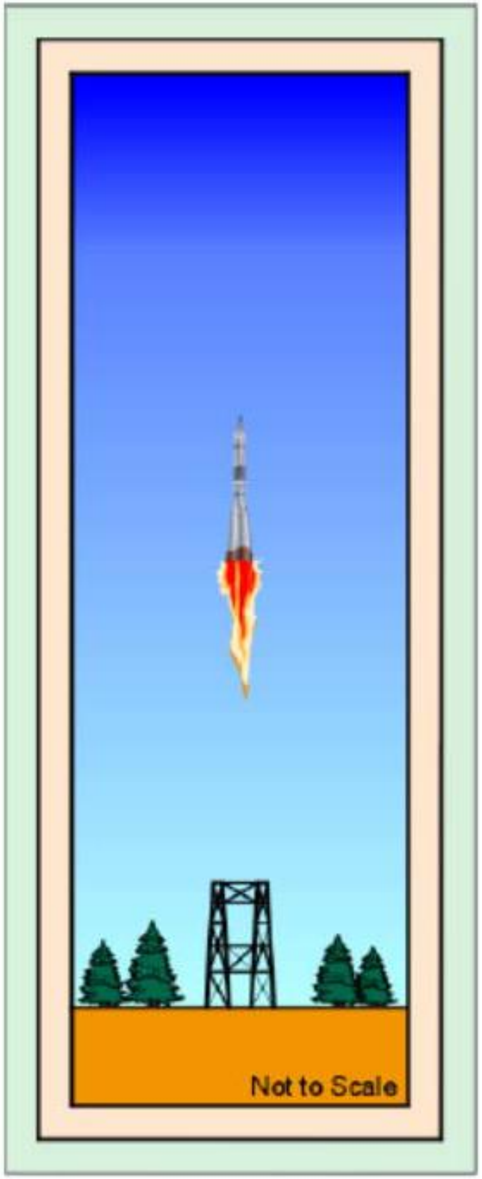
- but most notably:
  - (very) high variation of radioactivity concentration – ranging from less than10^{10} up to more than 10^{17} Becquerel (Bq) per m^3
    (1 Bq: one radioactive decay / one conversion per second,
    every human being carries about 8000 Bq in himself)
  - radionuclides with (very) high variations in „life span“
    (half-life: the time in which half of the „repository“ is being transformed) -
    example: ^{16}B: < $190 \cdot 10^{-12}$ seconds
    ^{232}Th: 14 billion years

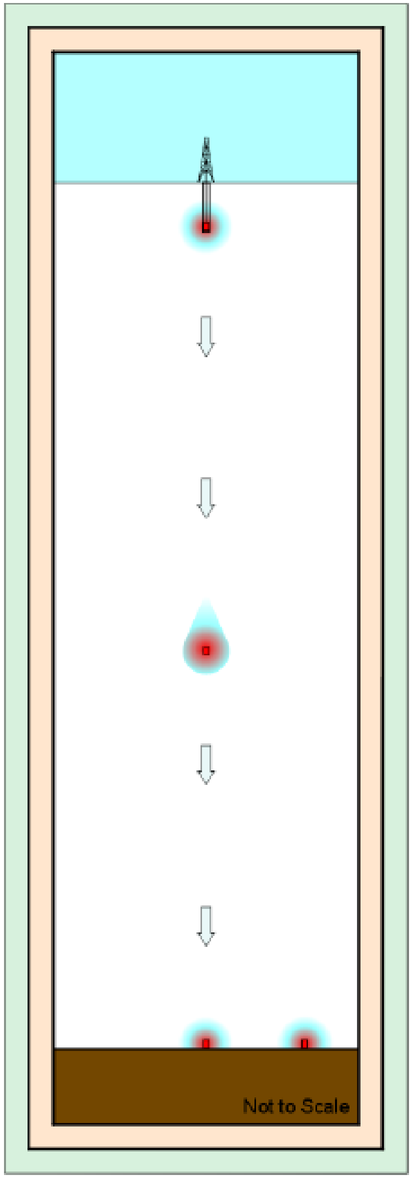
Categorization of radioactive waste (IAEA)



Options of disposal

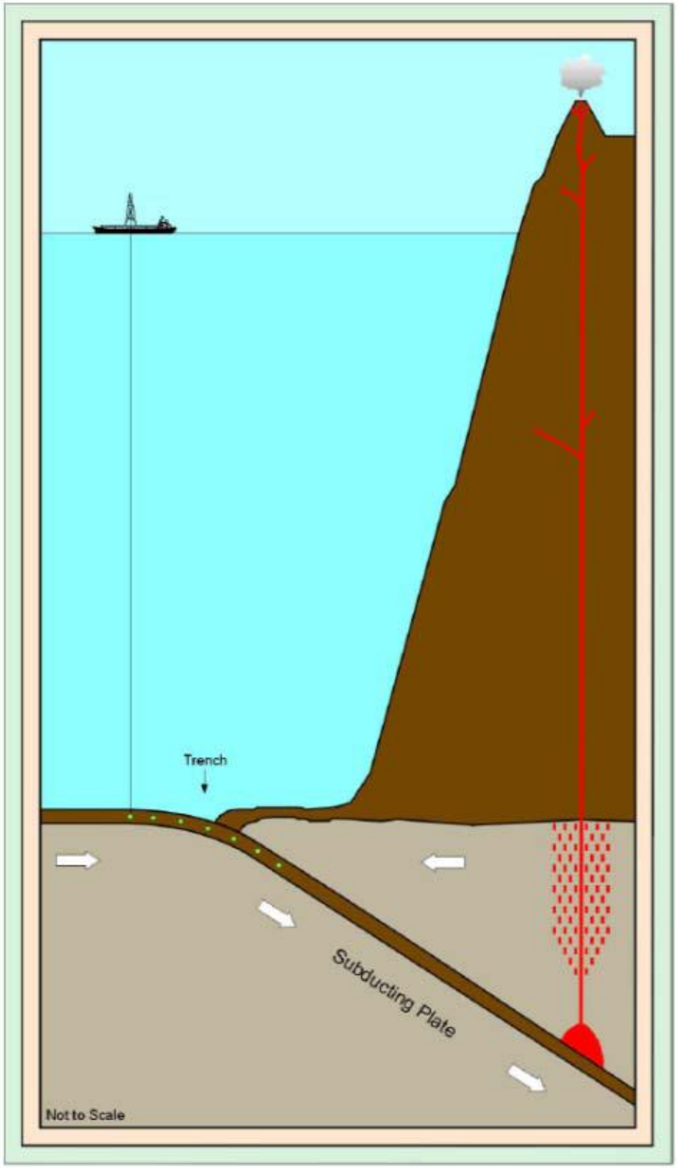
- Outer space
- „eternal“ ice sheet





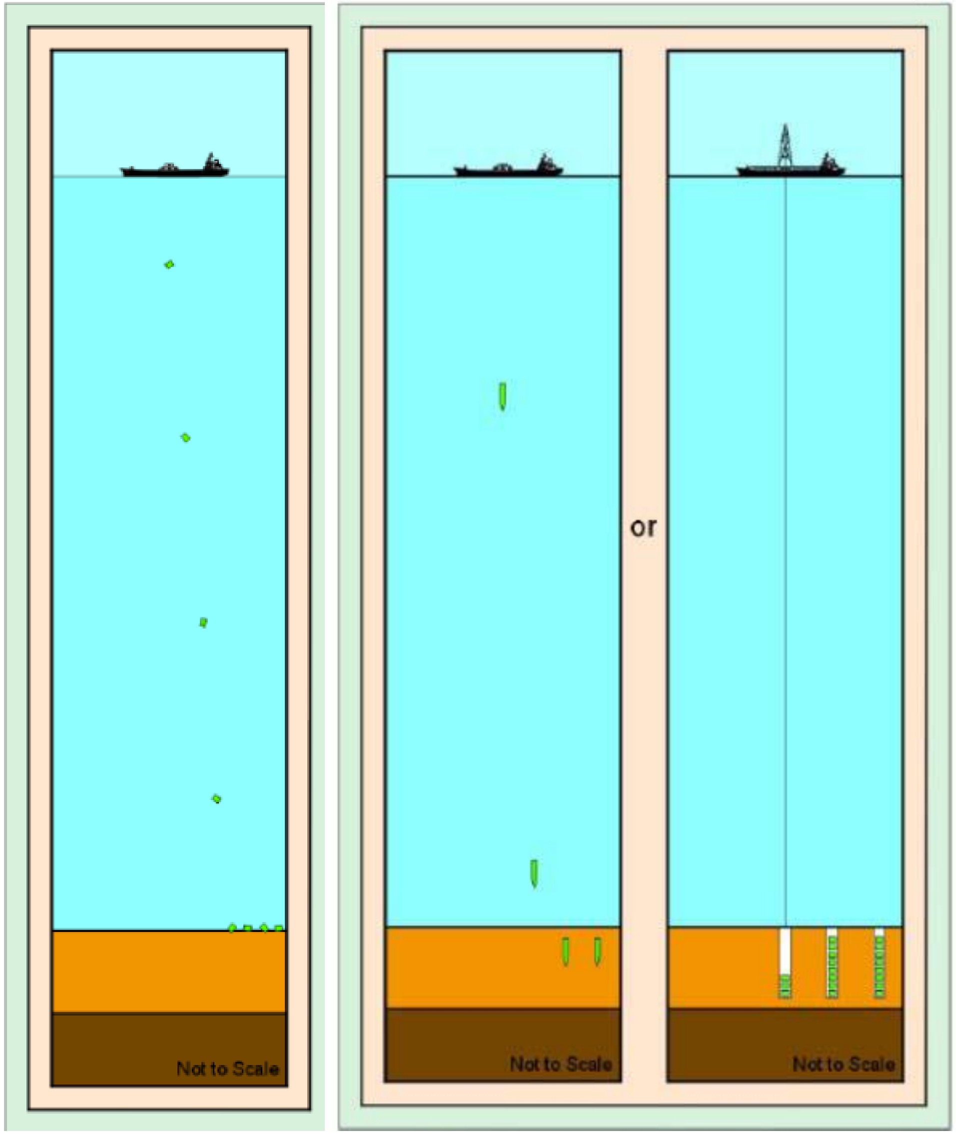
Options of disposal

- subduction zones



Options of disposal

- At sea
- Sub-seabed



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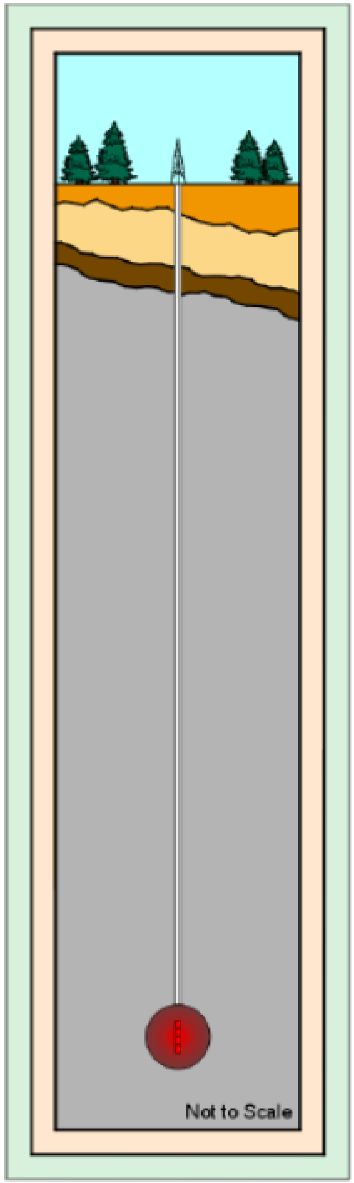
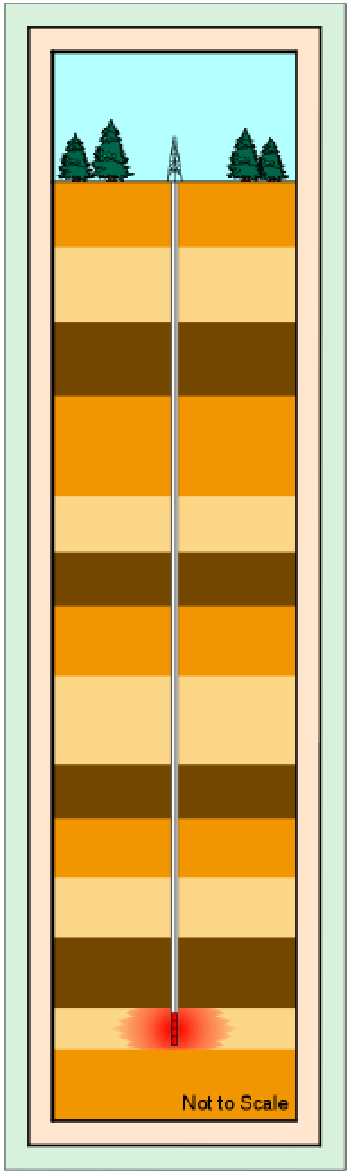
Options of disposal

- rock-melting by nuclear explosion
- injection





Options with focus on high-level (heat generating) radioactive waste

- ~~space disposal: risk, costs~~
- ~~disposal into „eternal“ ice: risk, international treaties~~
- ~~disposal into subduction zones (ocean floor): risk, international treaties~~
- ~~sea, sub-seabed: risk, international treaties~~

- long-term monitored storage at or near the surface

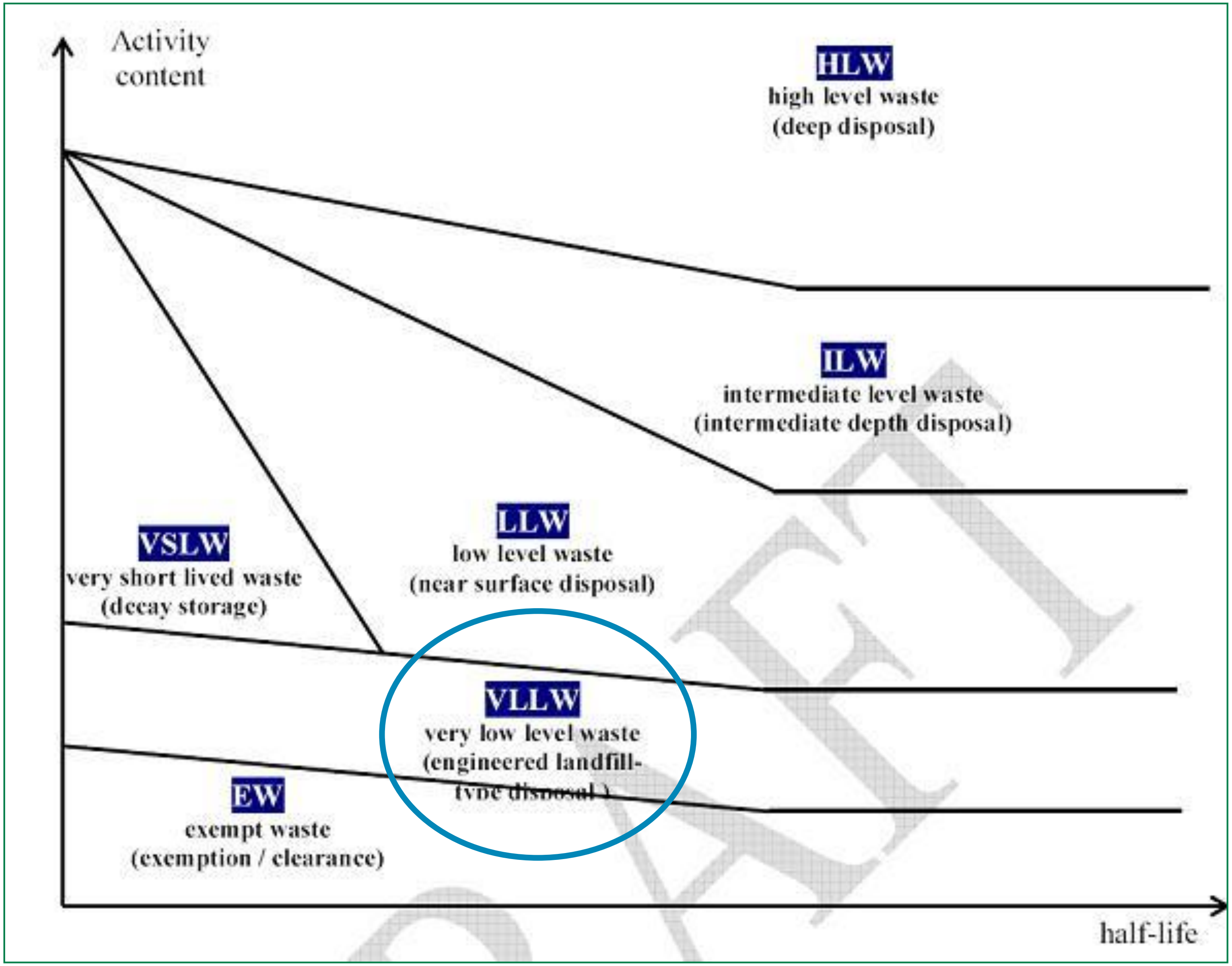
- disposal in deep geological formations (depth of several 100m) – retrievable?

Options of disposal for low- or medium-level radioactive waste

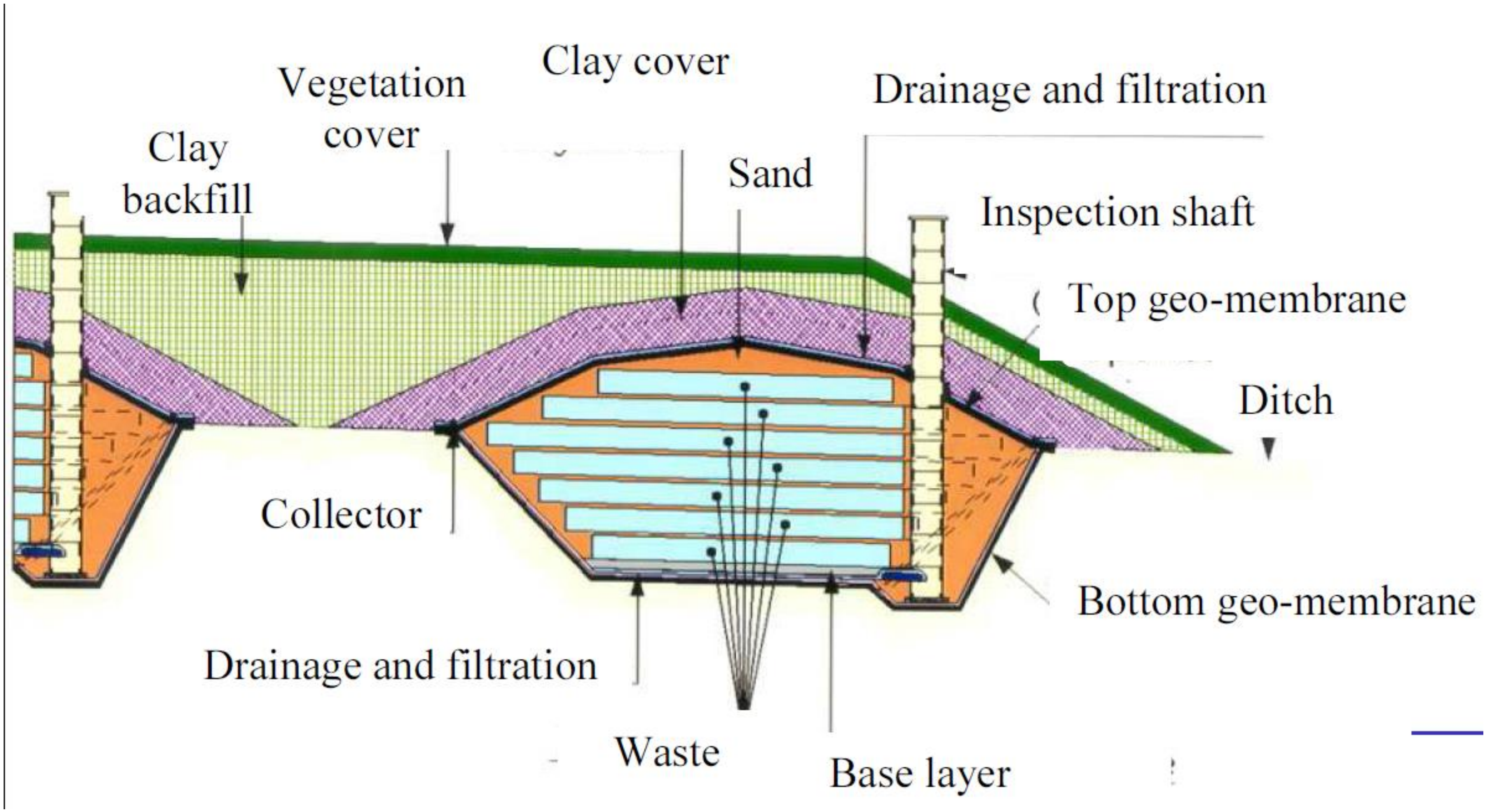
- short-lived waste:
  - clearance
  - storing until radioactivity fades
  - storage on the surface*)
- disposal at depths of some 10m*)

*) not intended in Germany

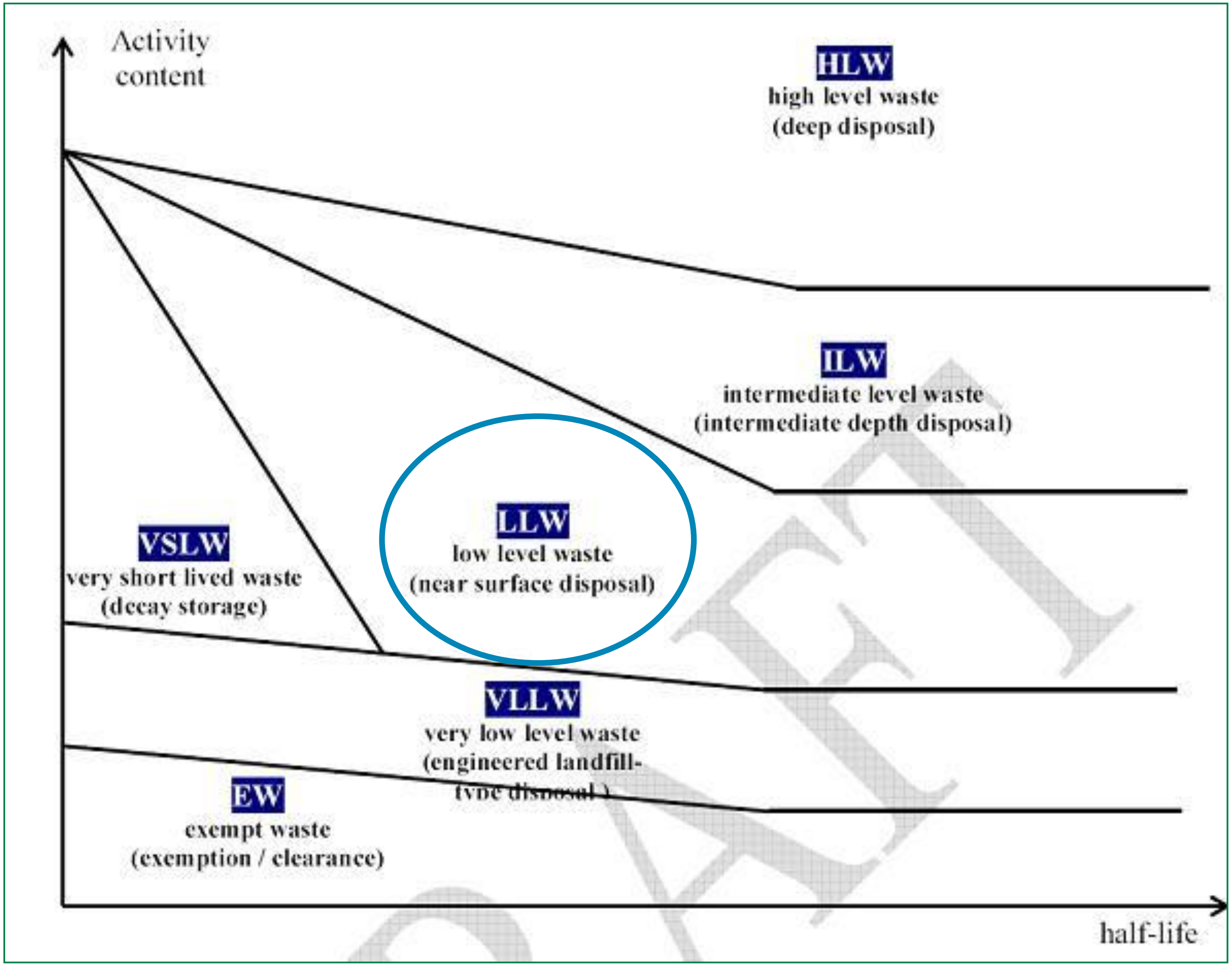
Categorization of radioactive waste (IAEA)



VLLW-storage site Morvilliers (F)

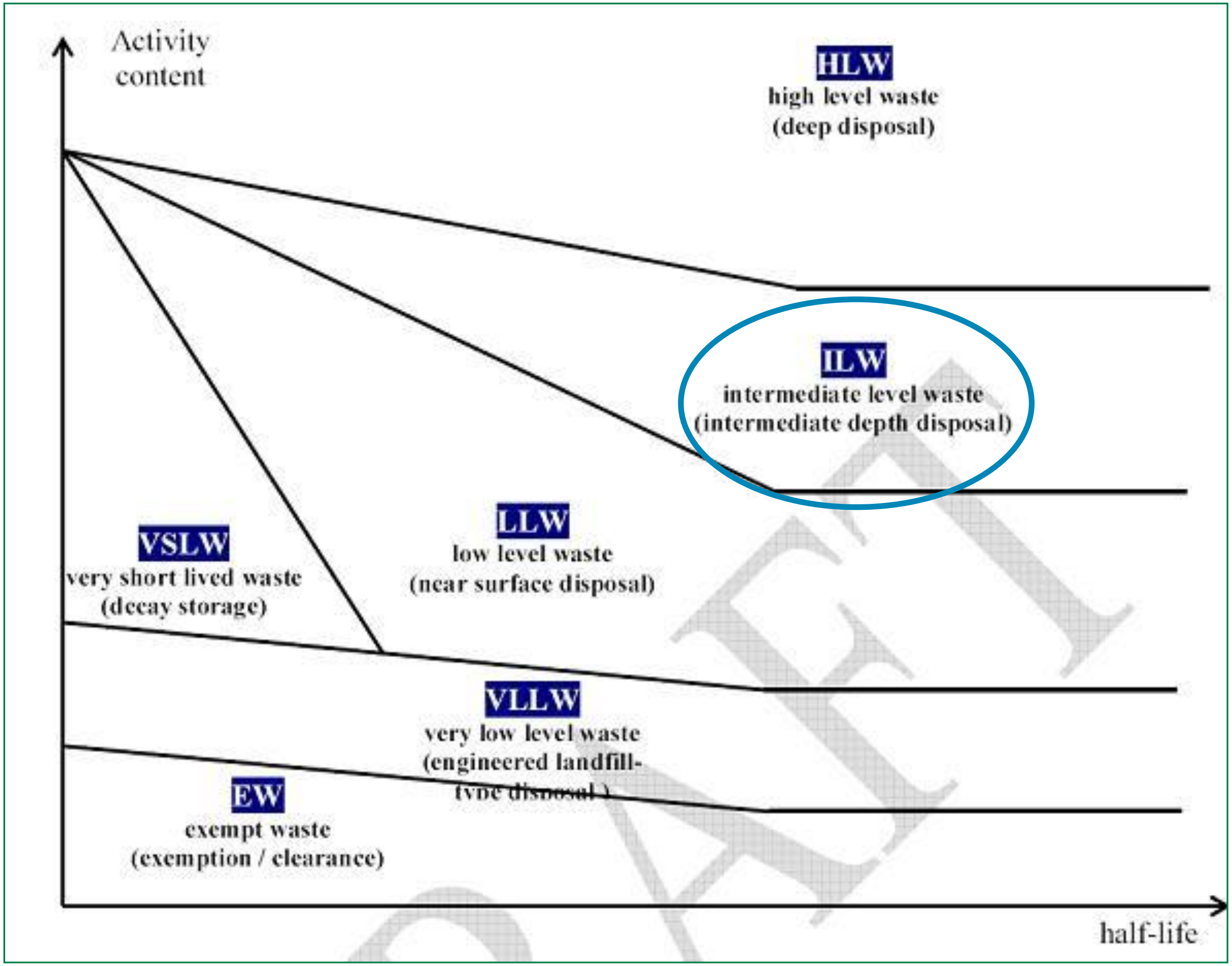


Categorization of radioactive waste (IAEA)



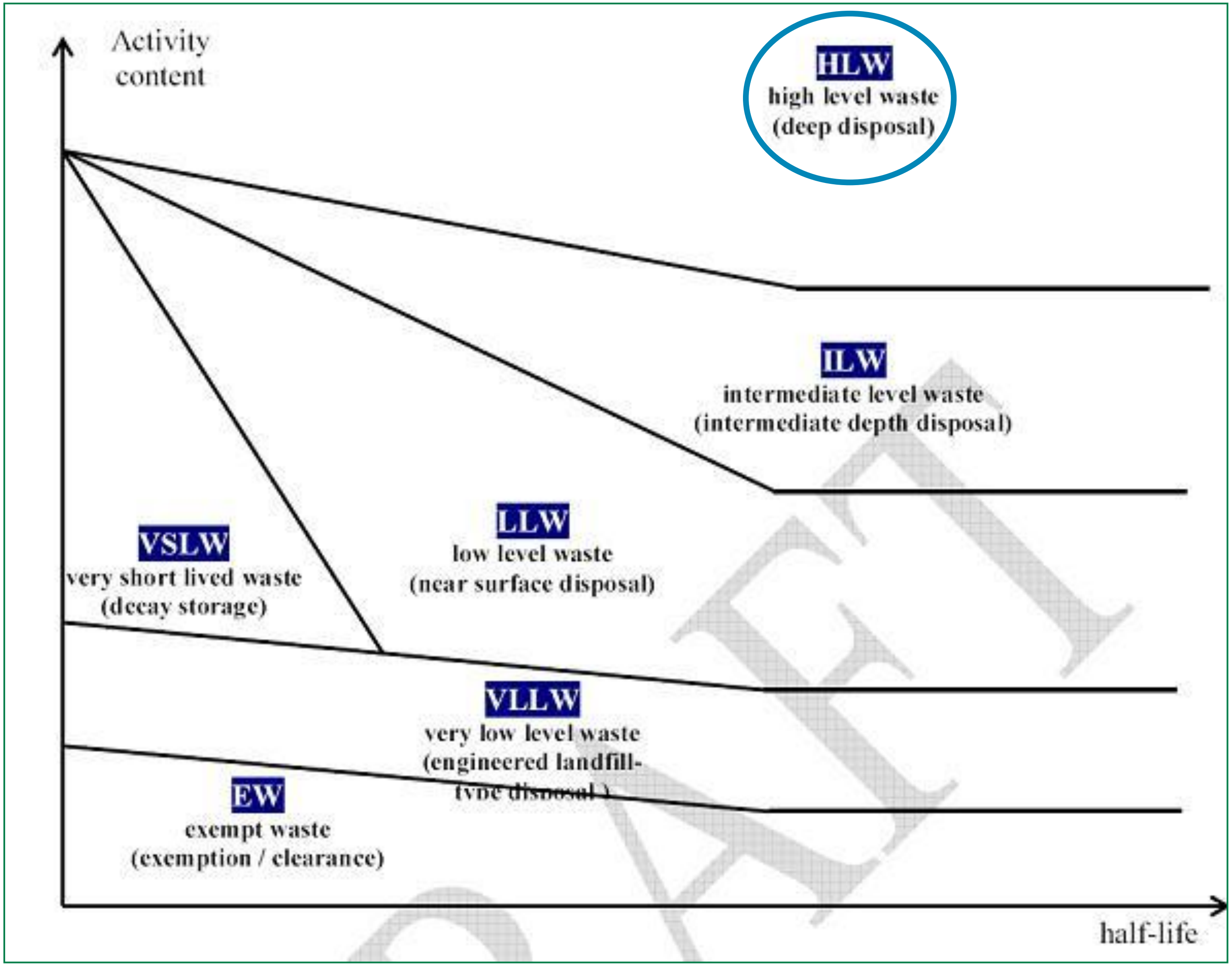
Surface short-lived waste disposal: El Cabril (Andalusia, Spain)

Categorization of radioactive waste (IAEA)



Intermediate-depth LILW disposal (60m): SFR (Forsmark, Sweden)

Categorization of radioactive waste (IAEA)



Deep LILW disposal: WIPP (Carlsbad, NM, USA)

Long-term SNF/HLW storage: HABOG (near Borssele, Zeeland, NL)

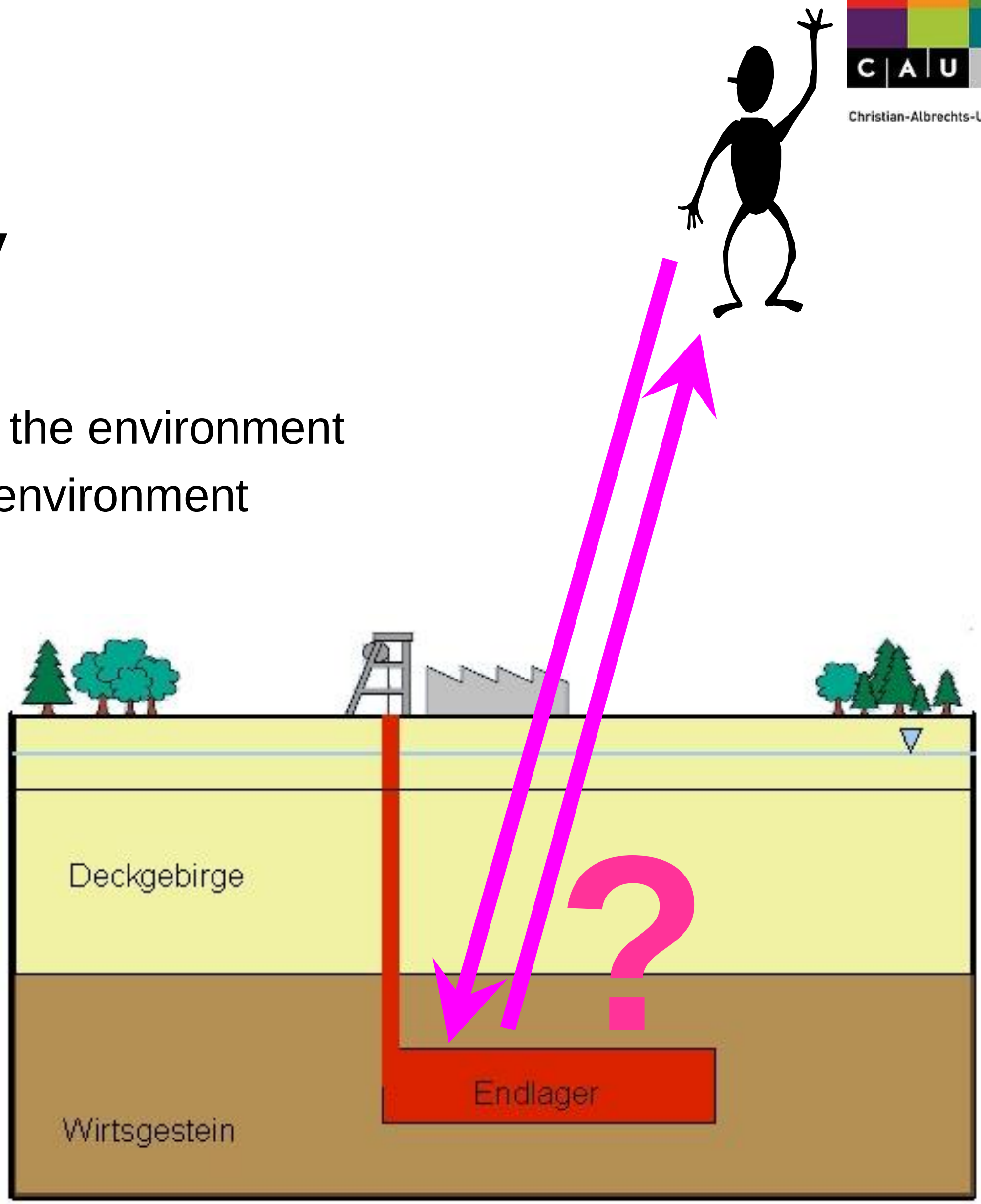
Deep ("geological") disposal

- no retrieval intended (making arrangements to allow retrieval are possible but they should not have a negative influence on safety)

- safety over long periods of time without human action ("passive safety")
  - **safety** independent from monitoring, maintenance, etc.
  - therefore no influence through economical or political developments (changes in human society take effect within decades, not within centuries!)
  - **fairness:** no burden for upcoming generations (but also limited freedom of choice)

Security / Safety / Certainty

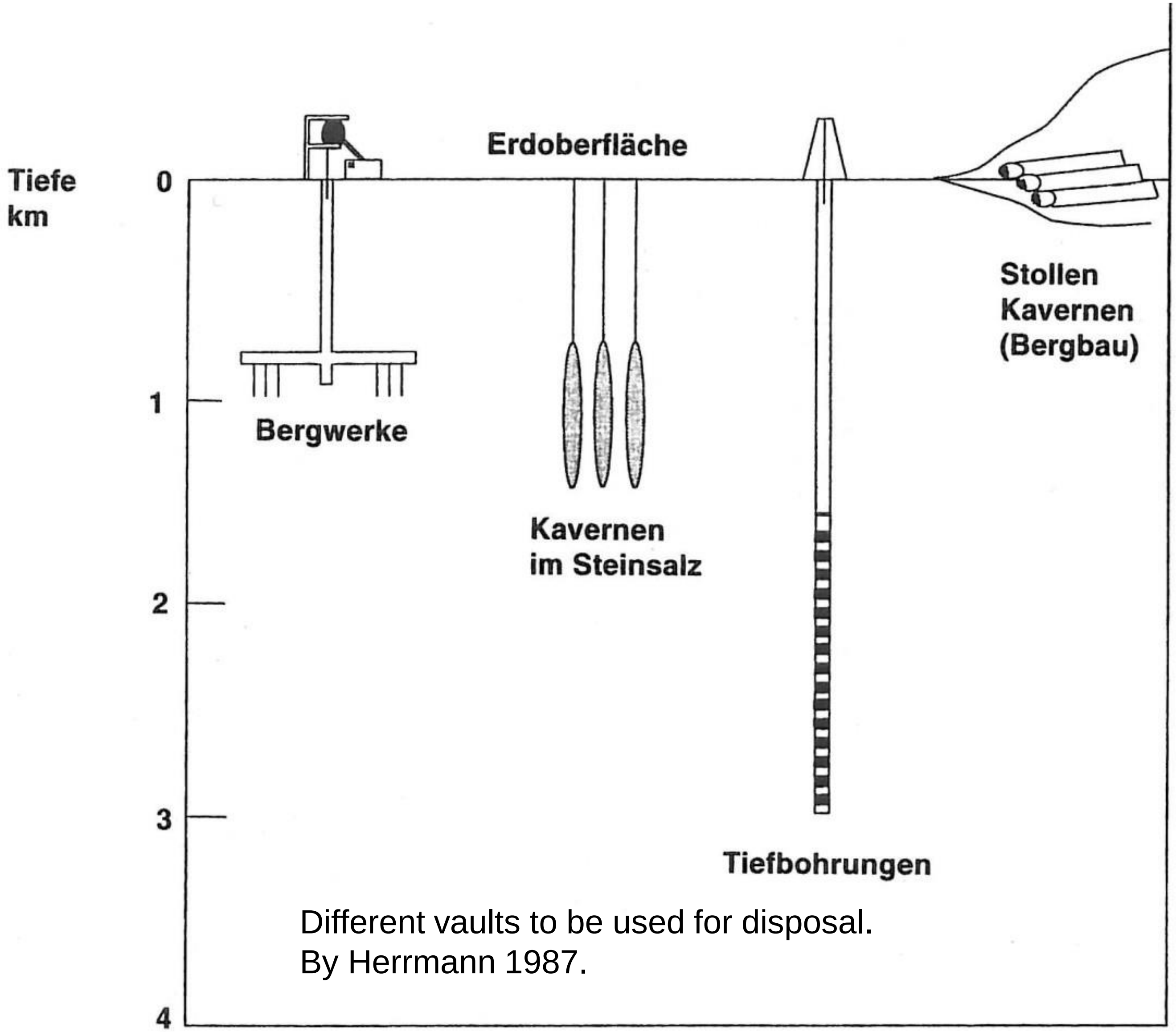
- Security – protection **from** the environment
- Safety – protection **of** the environment
- Knowledge = Certainty



Purpose of (deep "geological") disposal

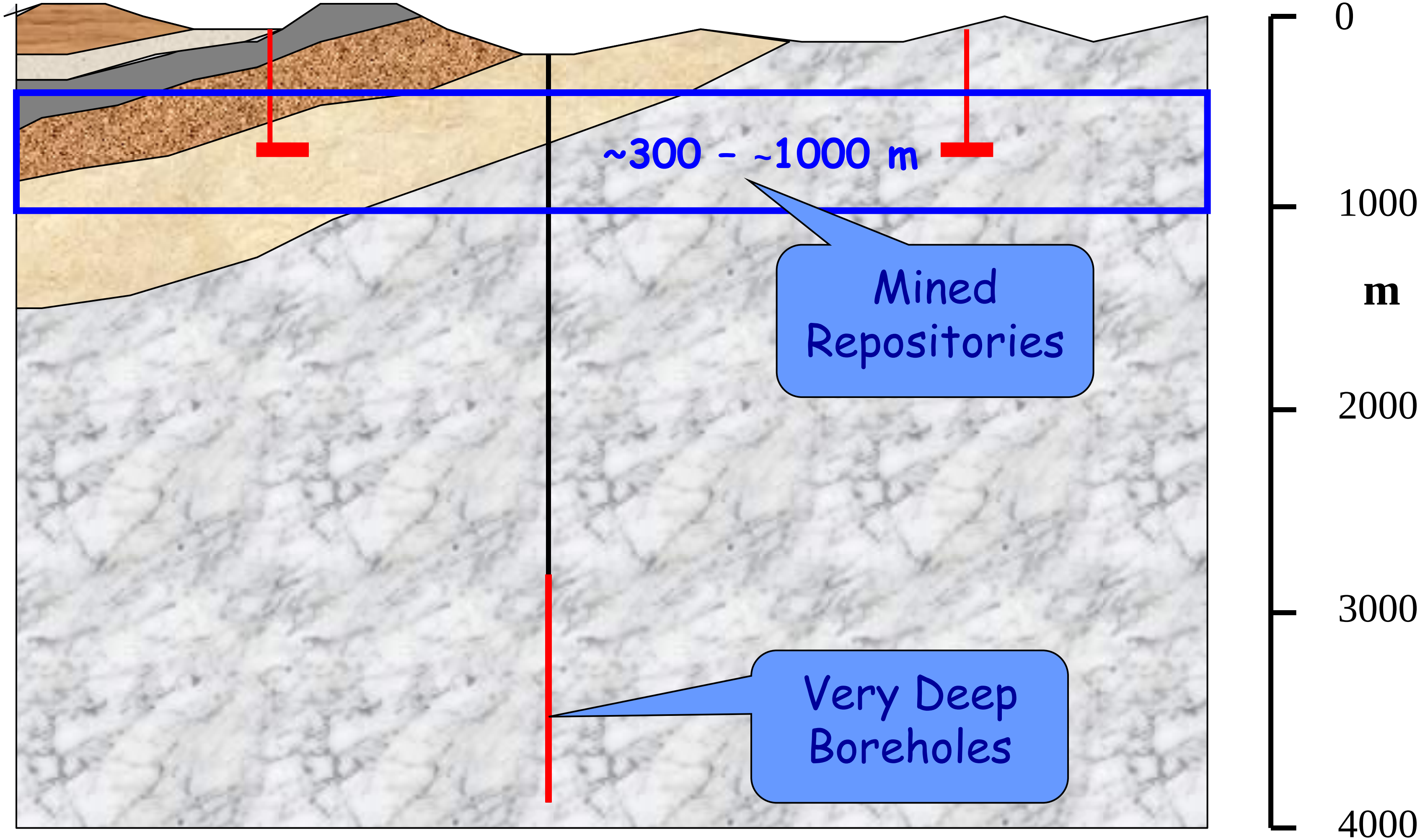
- **isolation** from the biosphere – access prevention
- **containment / confinement** over long periods of time
- if that isn't completely possible anymore: **retention**, with the aim to delay / attenuate the migration of toxic substances

- requirements: **stability** / predictability
  (mechanical, hydraulical, chemical)
- and of course: implementation / **mining feasibility**



Different vaults to be used for disposal.
By Herrmann 1987.

Deep geological repositories



Security models and safety measures

Main characteristics and safety functions:

- crystalline (KBS-3 – Sweden/Finland):
  - variable groundwater flows due to fractures, advective migration
  - long-term (>10^5 years) encapsulation in copper-covered container
  - stabilisation (chemical / mechanical) and migration attenuation by using bentonite buffer (swellable clay substance)
- clay:
  - saturated, no significant groundwater flow, migration dominated by diffusion
  - Containment (several 100 years) by container (claystone – France/ Switzerland) respectively super container (plastic clay - Belgium)
  - then migration attenuation via host rock and seals
- rock salt:
  - „dry“, no mobile waters, no migration
  - long-term (10^6 years) confinement by host rock and seals / compacted backfill
  - design of container dominated by handling (and retrieval) requirements

Safety measures – host rock – concepts for disposal

technogen
geogen

	isolation from biosphere, reduce likelihood of human access	stability (mechanical, hydraulic, chemical)	Containment of the waste	Attenuation of migration
crystalline	host rock overburden	canister, bentonite-puffer host rock	persistent fuel casks	fuel-matrix, bentonite buffer host rock
claystone	host rock overburden	host rock	[canister] – time limited!	host rock [overlying rock] seals
salt	host rock overburden	host rock	host rock seals	host rock [overlying rock] seals

Disposal strategies – end points (2)

long-term, monitored storage

- technically feasible, demonstrated
- main safety issue:
  human behaviour
  (no long-term guarantee)

- retrieval easily possible anytime (intended?)
- recommended especially in case of resources
  (vitrified residues from reconditioning are no rescources!)

- What time-frame? What to wait for?

disposal in deep geological layers

- technically feasible
- passive safety
  (without relying on human action)

- retrieval not intended, possibly expensive and difficult
- recommended for waste

- not to be realized before 2030, much more likely after 2040
- sufficient “time to wait”!

Could “retrievable” storage be a compromise?

A reasonable compromise?

- The options discussed so far contain strengths and weaknesses. Is there a reasonable compromise which combines the strenghts of both options and avoids their weaknesses?

- "The solution that seems to be emerging is that of **retrievable** storage in a facility that is designed for geological disposal, which is a **mixed approach**.

  - It relies on technical criteria (utilitarian),
  - is generally more publicly acceptable (libertarian) than direct disposal in the short term,
  - and ensures that the financial burden is borne by the current generation whilst not precluding decisions by future generations (social justice)."

(COMPAS Report)

The popular science variant.
Citations (really?) from Günther Oettinger

- „The repository that I imagine is a subterranean garage.“ (http://www.nwzonline.de/politik/niedersachsen/eu-fordert-ausbau-von-trassen_a_1,0,701374060.html)

- „The term „repository“ is deceptive. It is more like a subterranean garage… We will store the casks several hundred meters below the surface. If our predecessors are smarter und will find a better storage place, they could retrieve the casks again." (http://www.deutsche-handwerks-zeitung.de/oettinger-gegen-endlagersuche-in-baden-wuerttemberg/150/3092/75470/)

- „In my opinion the retrievability of nuclear waste is wise. In a few decades or maybe centuries it could be disposed in a smarter way or even be utilized… The Finns chose this path: they store the waste in hard rock, let‘s say some sort of subterranean garage, from which it may be retreived later on.“ (http://pressemitteilung.ws/node/434641)

Reasons: pros and cons

- long-term security
  - is ensured in the best possible way when no arrangements for retrievability are being made
    or
  - can not be guaranteed (as a matter of principle)
    → interference / revision possible by retrieval
  - possibly use of upcoming technology
- industrial and environmetal safety
  - retrieval leads to additional nuclear contamination
    or
  - this is to be rated inferior compared to the long-term exposure if a system failure occurs
- fairness (inter-generational)
  - disposal relieves future generations of their responsibility
    or
  - retrieval creates autonomy of decision in the future
- this and „future technology“ combined leads to:
  waste ***or*** resource?
- retrieval ***jeopardises*** security (from attacs)

Technical possibilities

- The terms „retrieval“ and „recovery“ are sometimes used synonymously and sometimes in contrast to each other.
  For example in the BMU-Safety Requirements:
  - „Retrieval means the planned technical possibiliy to remove the emplaced radioactive waste container from the repository mine.“
  - „Recovery means the removal from radioactive waste from the mine in case of emergency.“

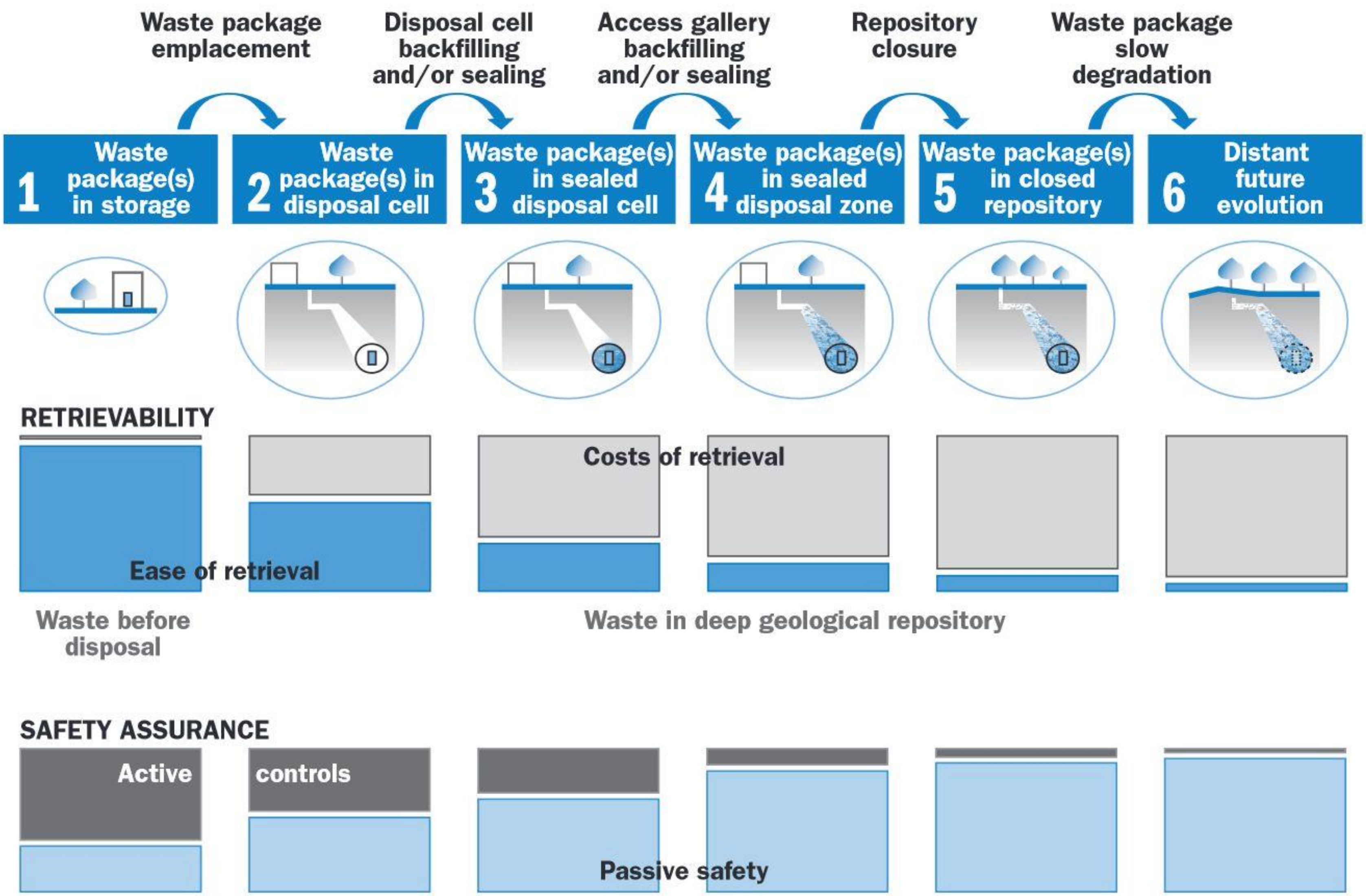
- *De facto* it is possible to…
  - keep the repository mine (or parts of it) open („subterranean garage“)
  - close the repository mine (or parts of it), but in a way that allows retrieval und makes it projectable
  - organise the closure in steps, so that the effort for retrieval accordingly increases stepwise

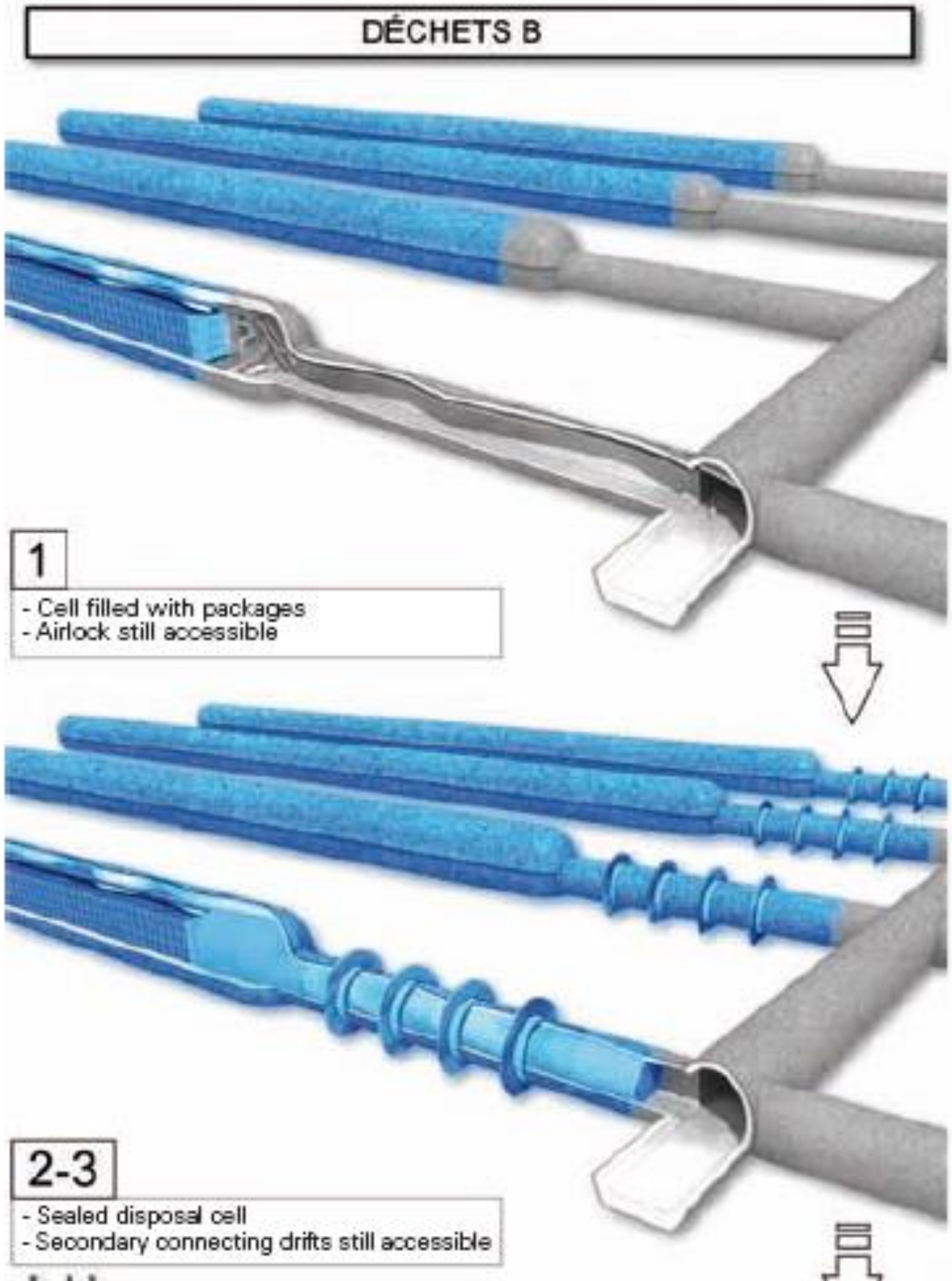
Keeping it open („subterranean garage“)

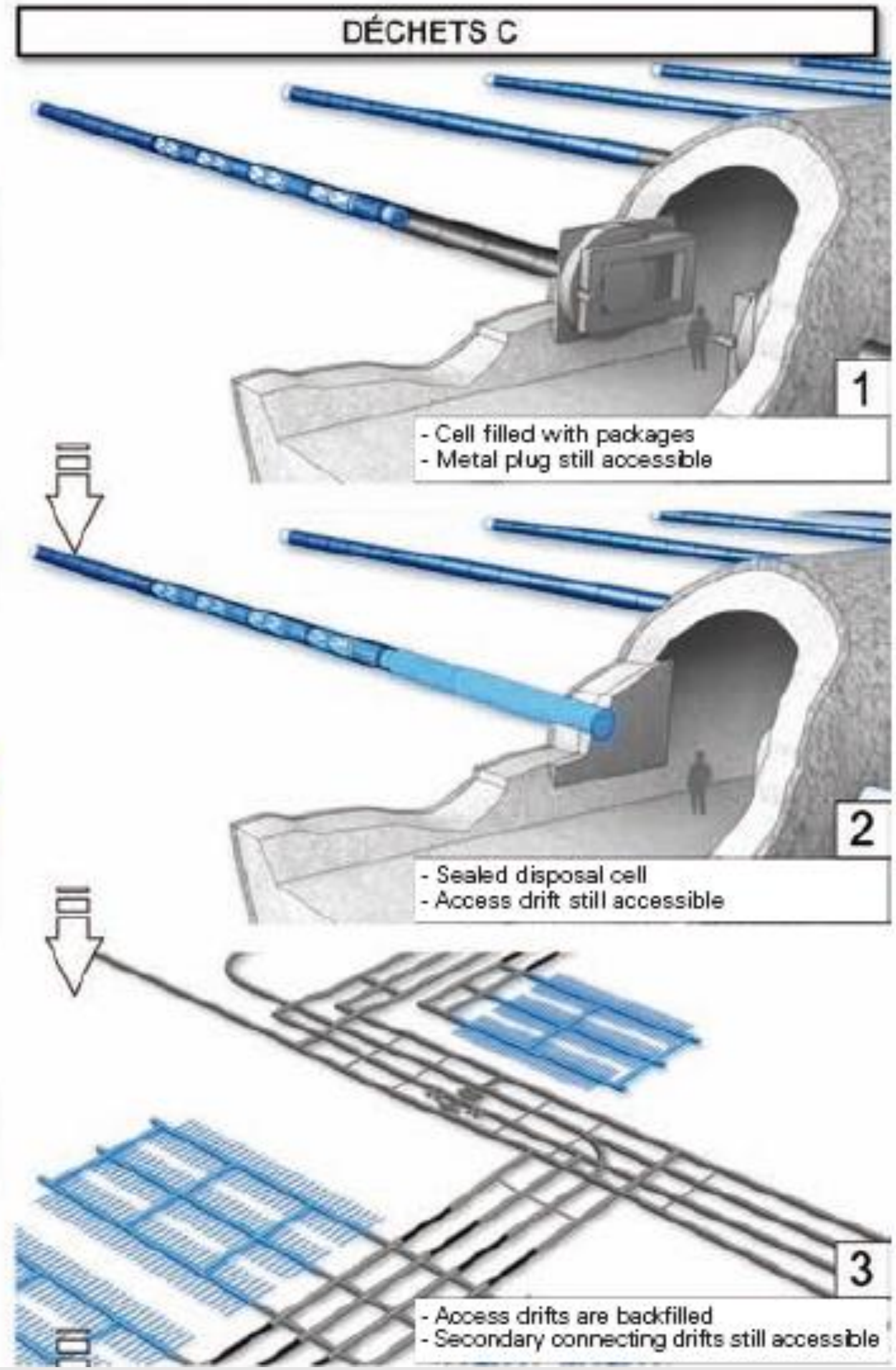
- at all times: keeping it open implies lining and maintenance
- long-term safety and security can only be achieved through closure
- monitoring necessary (protection of material suitable for weapons)
- entry of oxygen, fluids, microbes: corrosion,…

- applicable for different types of host rock
  - salt: difficult because: salt creeping, which normally is responsible for achieving closure, is a handicap in this case. High temperature (the waste is the source of heat) which would accelerate the salt creeping will complicate the retrieval.
  - clay stone: long lasting contact with the mine air → dehydration, acidification, stability problems

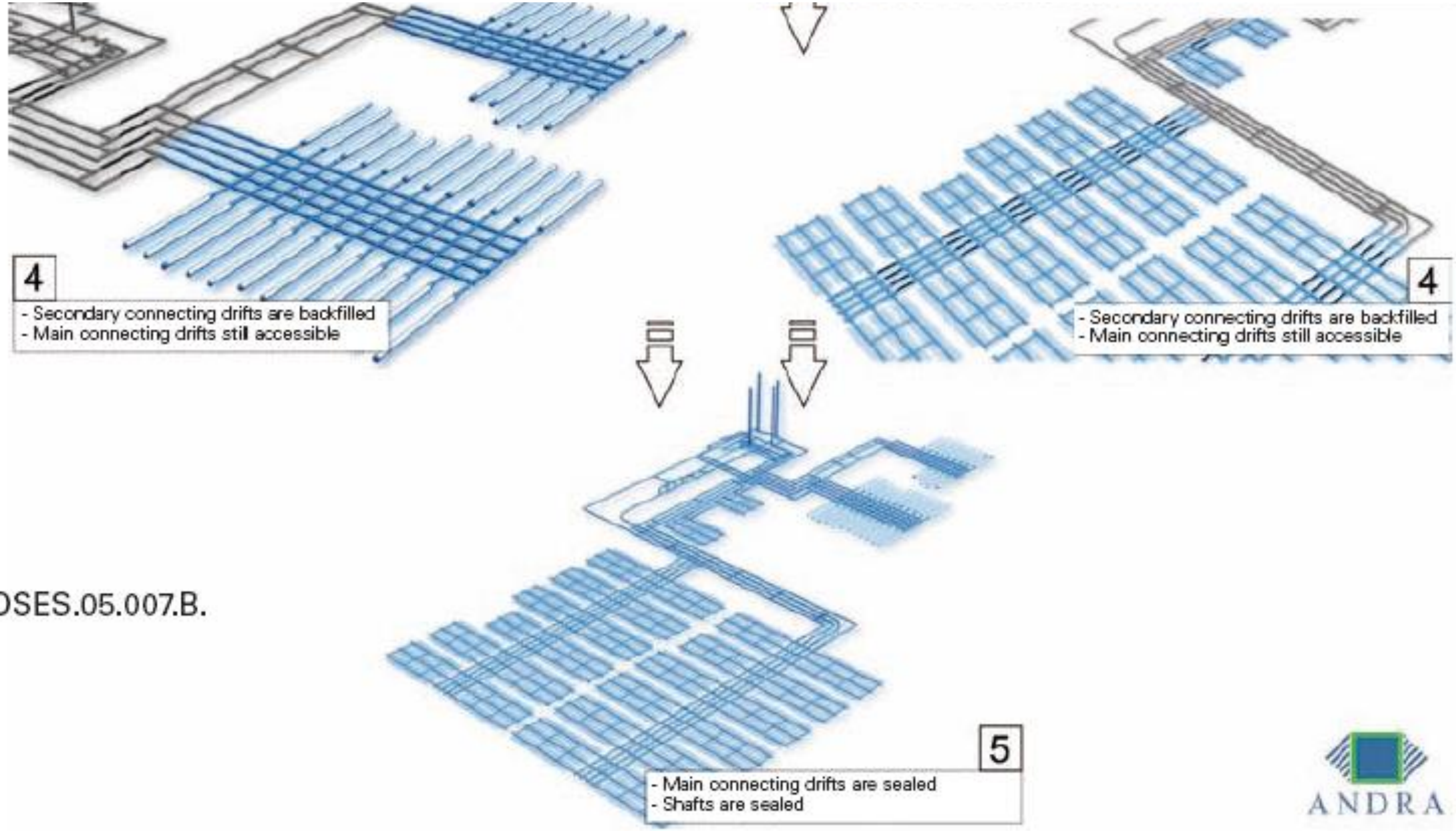
➢ conclusion: always consider the trade-off between competing goals!


Waste package emplacement
Disposal cell backfilling and/or sealing
Access gallery backfilling and/or sealing
Repository closure
Waste package slow degradation
1 Waste package(s) in storage
2 Waste package(s) in disposal cell
3 Waste package(s) in sealed disposal cell
4 Waste package(s) in sealed disposal zone
5 Waste package(s) in closed repository
6 Distant future evolution
RETRIEVABILITY
Costs of retrieval
Ease of retrieval
Waste before disposal
Waste in deep geological repository
SAFETY ASSURANCE
Active controls
Passive safety





Déchets B: ILW in concrete containers
Déchets C: HLW in steel containers


4
- Secondary connecting drifts are backfilled
- Main connecting drifts still accessible
4
- Secondary connecting drifts are backfilled
- Main connecting drifts still accessible
5
- Main connecting drifts are sealed
- Shafts are sealed
DSES.05.007.B.
ANDRA

Designing the concept for a nuclear waste repository (France)

Dossier 2005:

The whole process could take place over a period lasting from several decades to several hundred years if required. The progressiveness of closure gives the possibility of putting into place a staged decision-making process and keeps at all times the possibility of returning to the previous stage. *The progressive operating plan outlined above is by no means the only possible scheme; more stages or different durations could be considered. The modular design proposed for the repository and the flexibility offered for its operating mode allow the operating plan to be adapted by taking into account the knowledge of the repository's condition provided by observation.*

de facto reviewed: a time-frame from 100 to 300 years

Germany: retrieval (during operating phase!) in rock salt (preliminary safety analysis Gorleben VSG)

- generally: reversed waste emplacement process
  - Re-excavating of main drifts and crosscuts in alignment to a given procedure plan
  - excavation of interconnected drifts for retrieval
  - cooling of excavated areas for retrieval
  - uncovering the repository casks
  - pulling the repository casks to areas for retrieval
  - transportation of the repository casks underground and on the surface

- problems:
  - mine ventilation (temperature!): allows retrieval within 40 years
  - rock mechanics (temperature!)
  - radiology / monitoring

Summary:
retrievability is a relative term

- progress in time:
  emplacement, closure of emplacement fields, closure of mine
- after closure: retrieval only possible with mining technology
  BUT: keeping the mine open for a long time period will affect safety and security!
- changes of the condition of the repository over time
  (fastest in salt, slowest in crystalline rock), changes in temperature

- there is a **trade-off** in any case:
  - requirements for retrieval might compete with essential safety meassures!
  - conflict with access protection (security)!