Metallic Mercury Long-Term Storage Possibilities / Options

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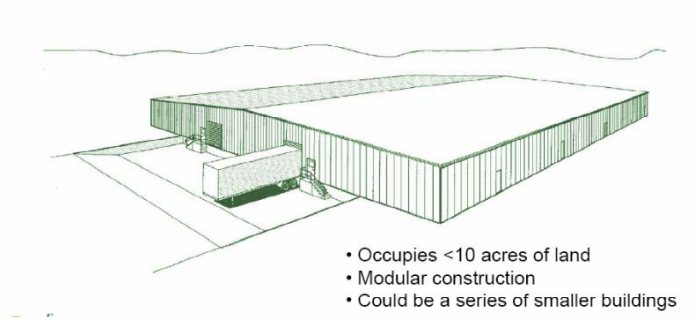
with contributions by Sven Hagemann

Who is GRS (‚Plant & Reactor Safety Ltd.‘)

- Non-profit, independent expert and research organization
- Assess and improve safety of technical facilities
- Focus on nuclear safety and waste management
- Customers: Ministries and authorities, European Commission
- Technical support of Federal Ministries conc. safety of chemicals, e.g. Mercury

Mercury Long-Term Storage: General Options



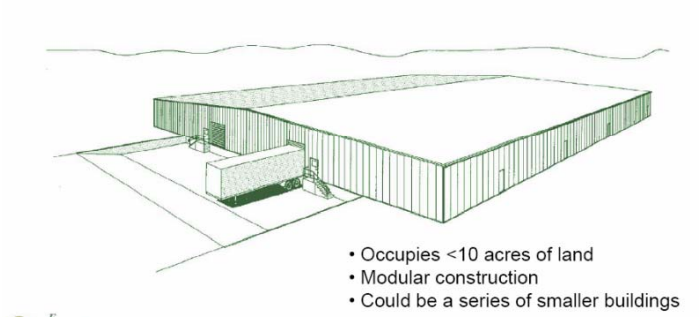
Warehousing **Underground Disposal** **Deep Injection**

+ Additional Option: Stabilization

Not considered: Surface Landfill

Mercury Long-Term Storage: Warehousing - Features

- Investment app. 10 Mio US$
- Waste still in biosphere
- Dry climate required



- Safety dependent on political & economic constraints
- US concept for app. 100 yrs.
- No permanent solution
- Current proposal of AIT

Mercury Long-Term Storage: Deep Injection - Features

- Investment costs unknown
- No control after injection
- Long-term safety assessment problematic
- Suitable geological situation needed
- Several applications worldwide (but no Hg) with different success

Mercury Long-Term Storage: Underground Disposal - Features

- Investment costs strongly variable
  (e.g. new facility / abandoned mine)
- Long-term safety assessment
  (broad experience)
- Suitable geological situation needed
  (e.g. salt, hard rock - optionally combinations)
- Several facilities with positive experiences
  since decades (esp. in rock salt formations)
- Operational safety must be guaranteed
- Combination with other hazardous wastes
  recommended

Background: EU Storage Obligation for Metallic Mercury

Regulation allows only few storage options, e.g.:

- Temporary or
- Permanently in
  - Salt mines*) or in
  - Deep underground hard rock formations**)

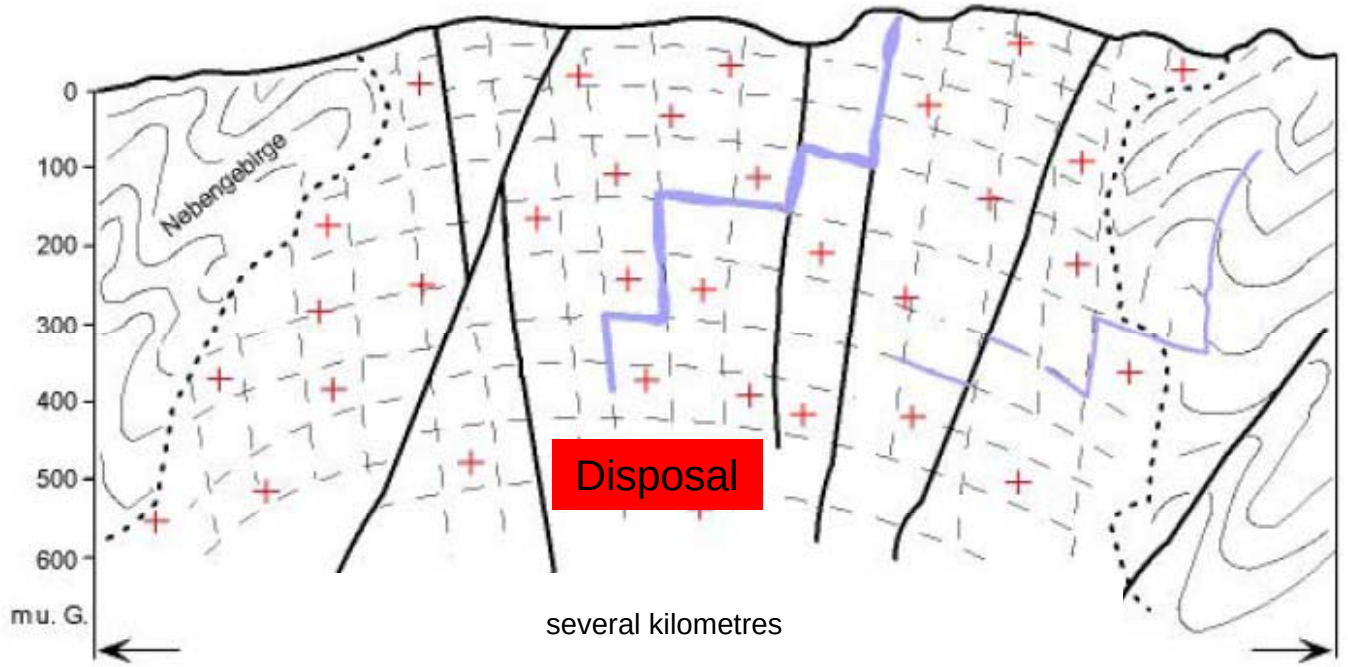
*) adapted for the disposal of metallic mercury

**) providing a level of safety and confinement equivalent to that of salt mines

Host Rock Properties – Comparison

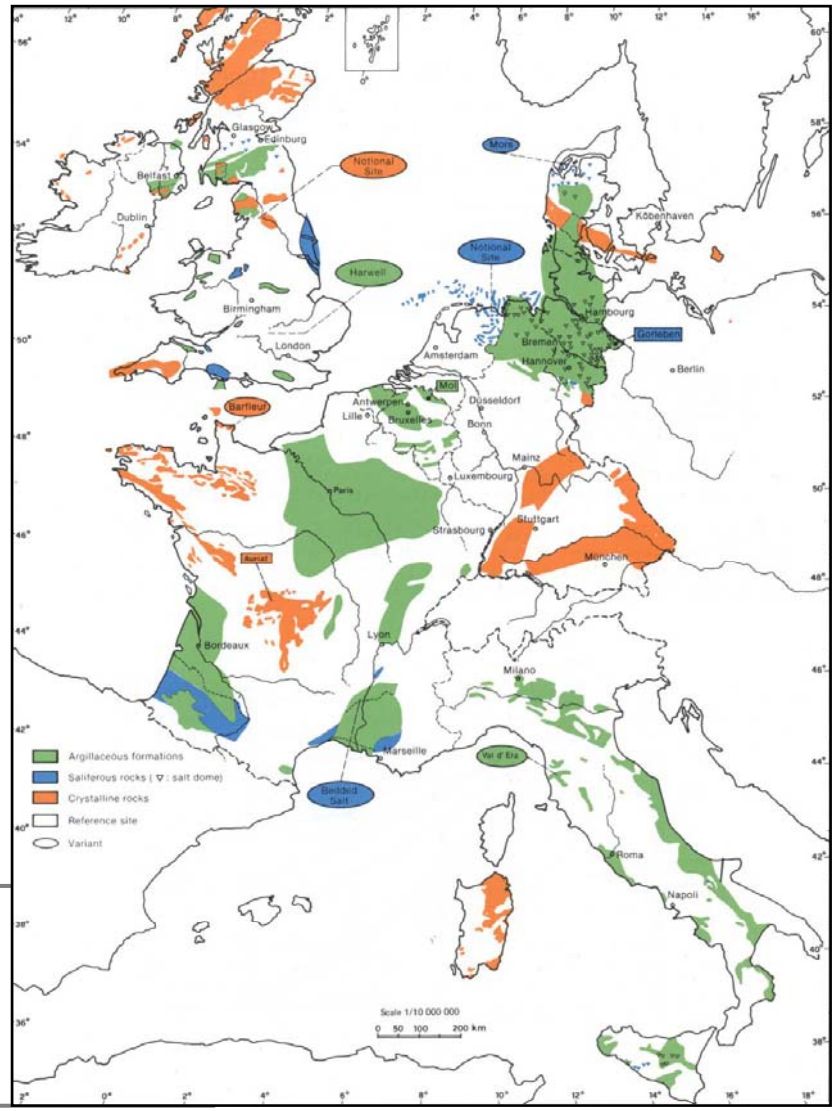
Properties	Rock Salt	Clay / Claystone	Crystalline (e.g. Granite)
Thermal Conductivity	high	low	medium
Hydraulic Conductivity	nearly impermeable	very low - low	very low (without joints) - permeable (jointed)
Mechanical Strength	medium	low - medium	high
Deformation Behavior	viscous (creep)	plastic - brittle	brittle
Stability of Cavities	self-stability	timbering necessary	high (without joints) - low (intensively jointed)
In-situ-Stress	lithostatic isotropic	anisotropic	anisotropic
Solubility	high	very low	very low
Sorption Capability	very low	very high	medium - high

Crystalline Rock - Features



- High rock permeability in jointed areas
- Heterogeneous distribution of hydraulic conductivity
- Strong significance of technical barriers

Potential Host Rocks in Western Europe (PAGIS 1984)

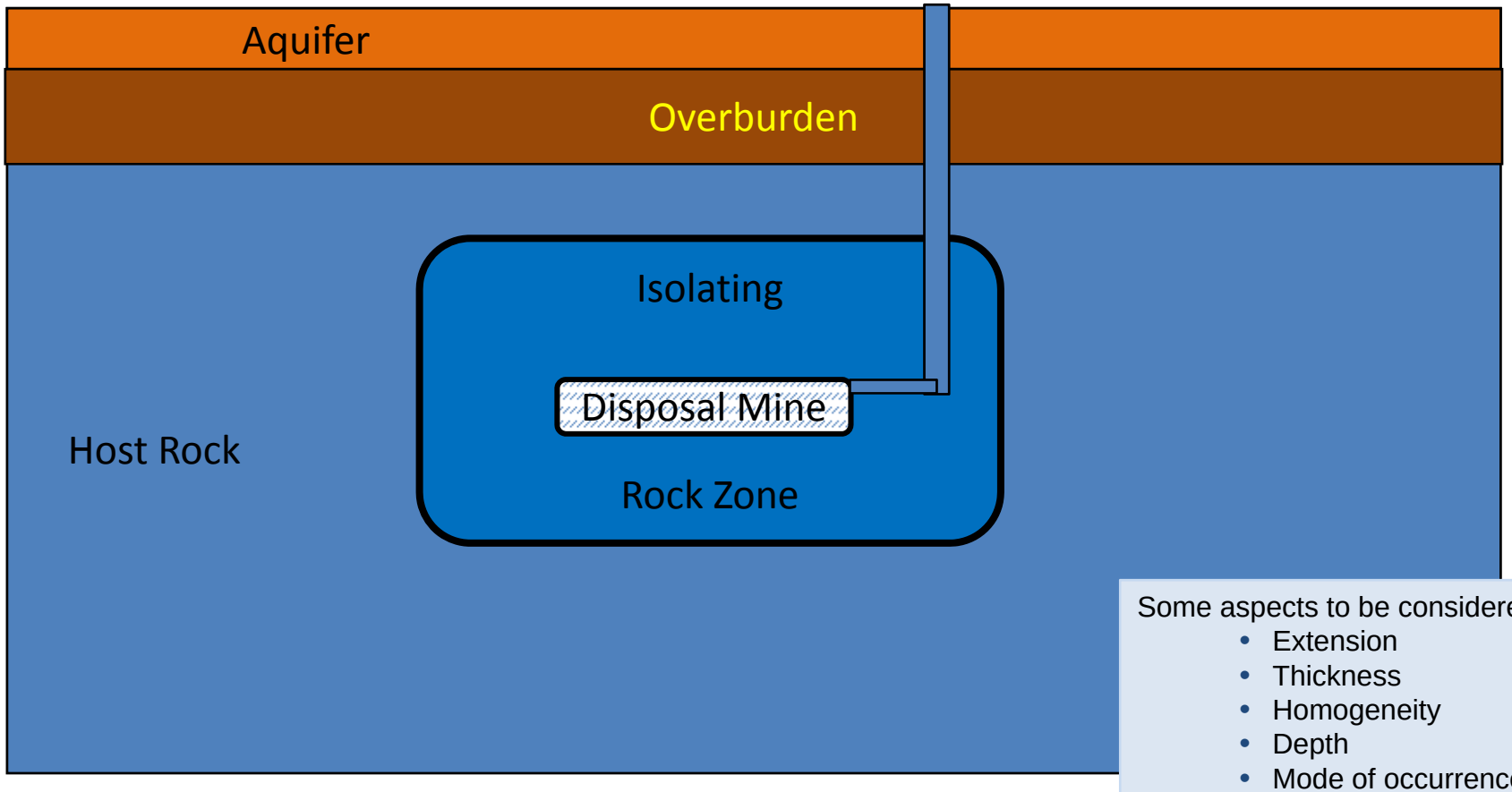


Salt formations

Clay formations

Crystalline

Concept of Complete Inclusion



Some aspects to be considered:

- Extension
- Thickness
- Homogeneity
- Depth
- Mode of occurrence
- GW-conditions

Host Rock Type - Rock Salt

Properties of Rock Salt

- Mechanical stability
- Viscoplastic behavior
- High creeping capability
- Low porosity
- Low permeability
- High thermal conductivity
- Low water content

Advantages for Underground Disposal

⇒ Construction of large cavities without special lining

⇒ Fast closing of cavities

⇒ No connected fissures and fractures

⇒ Self-healing of fractures

⇒ Negligible transport of fluids and gas

⇒ Fast removal of heat

⇨ Rapid and complete inclusion of wastes

Host Rock Type - Rock Salt

Additional advantages of rock salt formations

- High persistence of rock salt deposits
- Salts of Zechstein-age within salt domes since app. 250 mio years without contact to aquifers
- Deposits in geological stable regions with low earthquake activity
- Large accumulations of host rock, esp. in salt domes
- Long lasting experience from mining
- Numerous & widespread deposits (low conflict of interests)
- Effects of earthquakes in salt generally lower*)

*) but high seismicity will be an overall exclusion criterion!

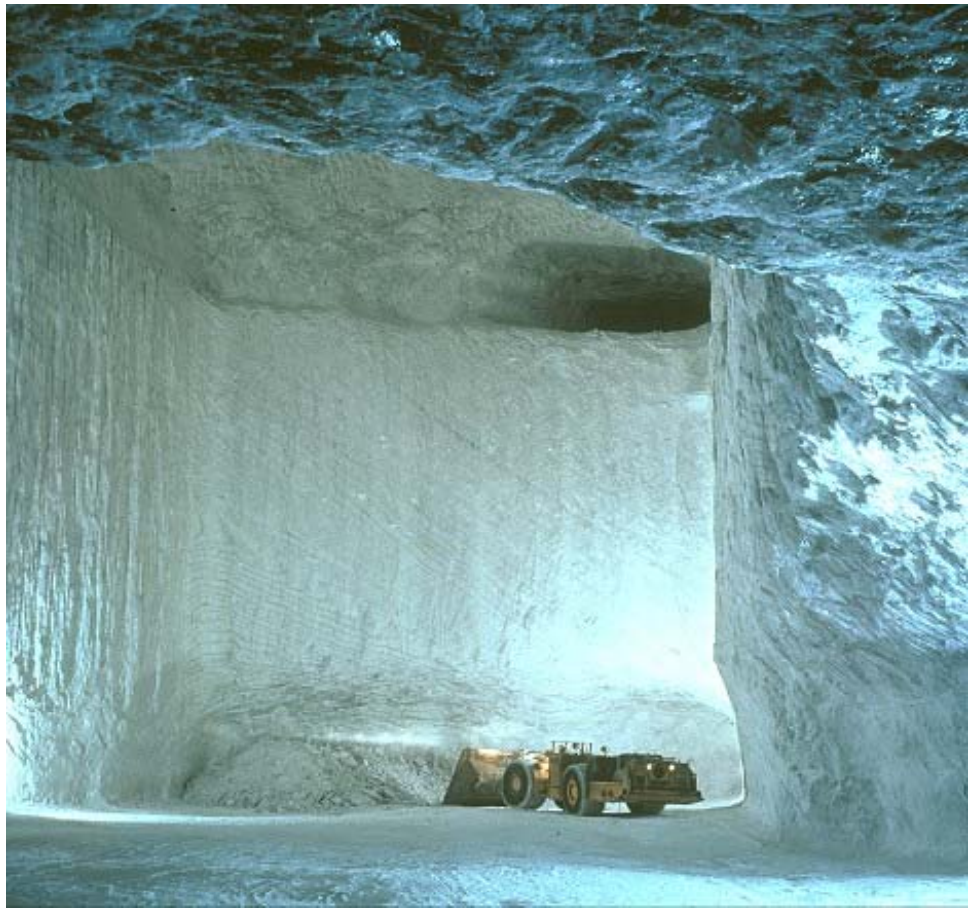
Host Rock Type - Rock Salt

Disadvantages of rock salt

- High water solubility*)
- Low sorption capacity
- Low gas permeability
- Geological complex structure of salt domes

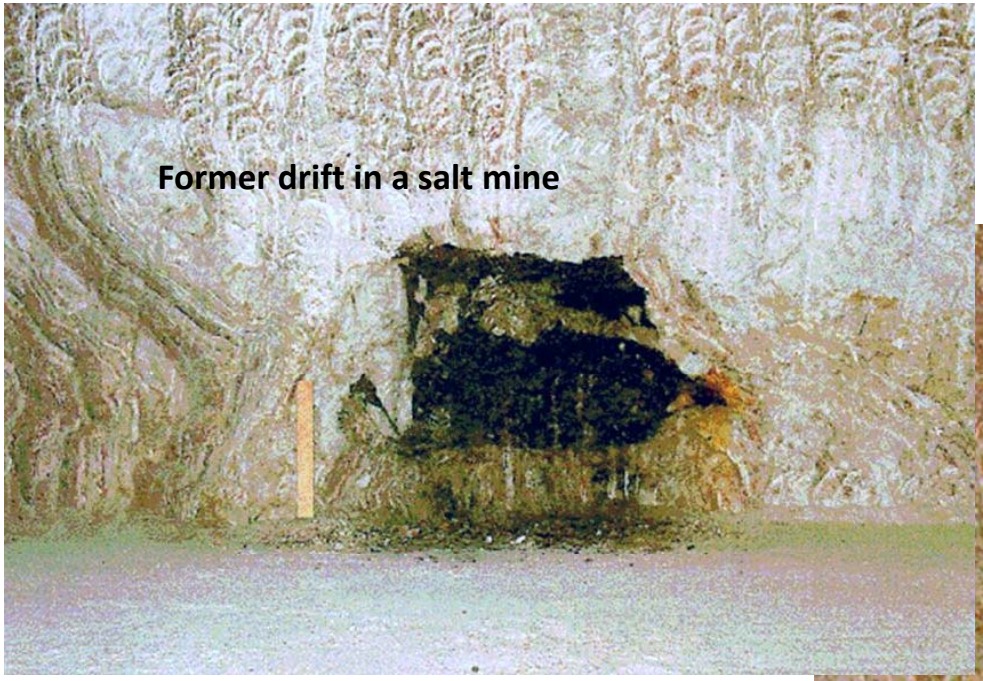
*) original reason for prohibition of fluids!

Why Rock Salt?

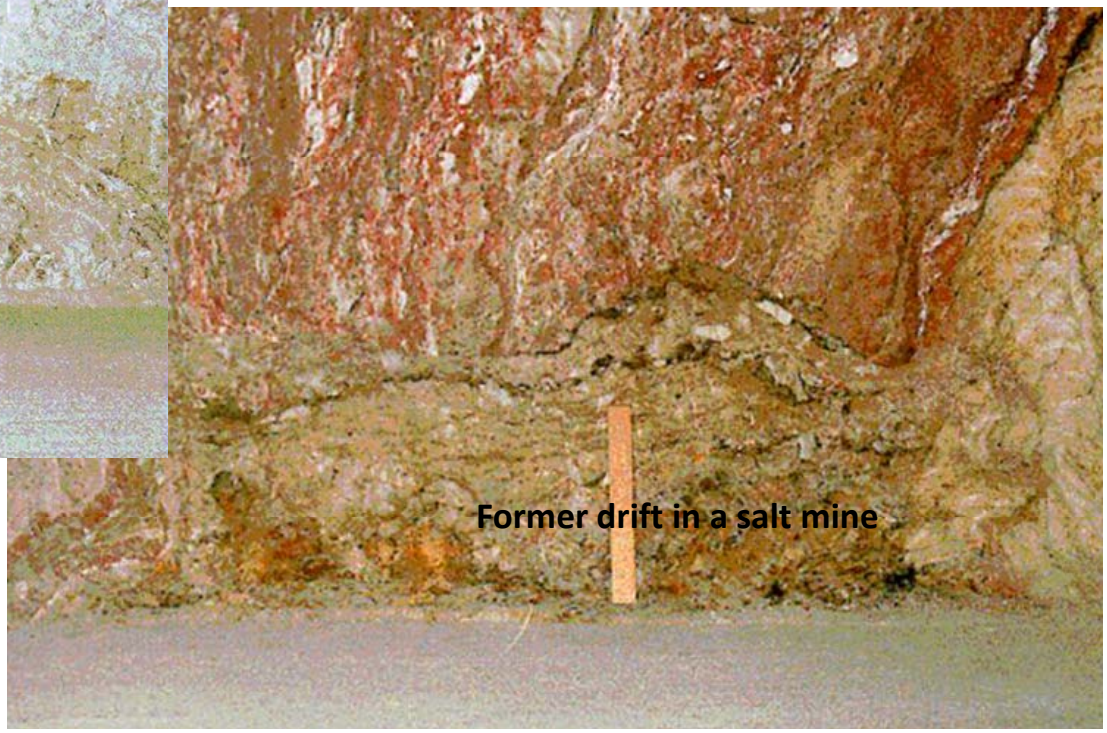


Large and stable cavities

Concept of Complete Inclusion

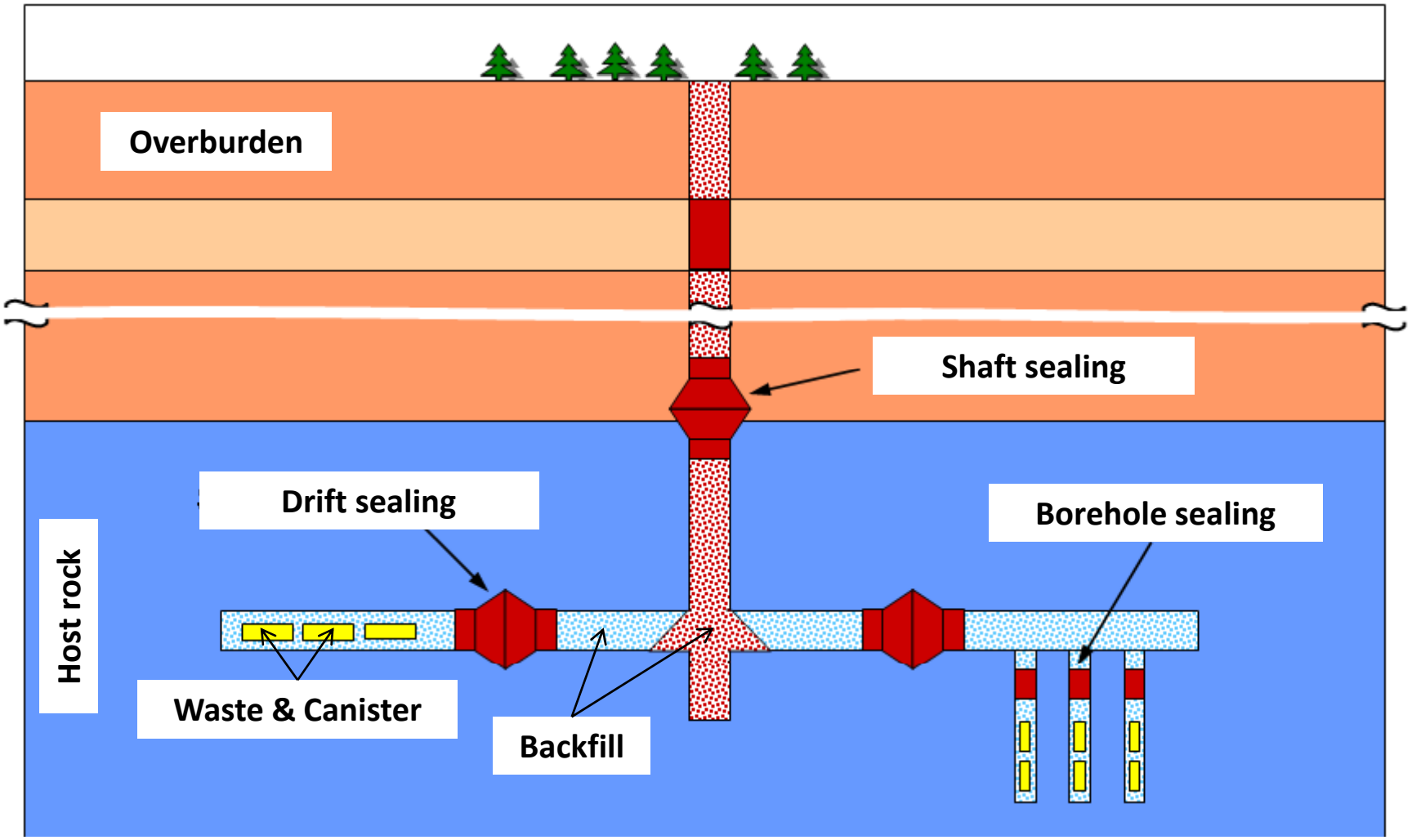


Unique rock properties,
esp. plastic behavior



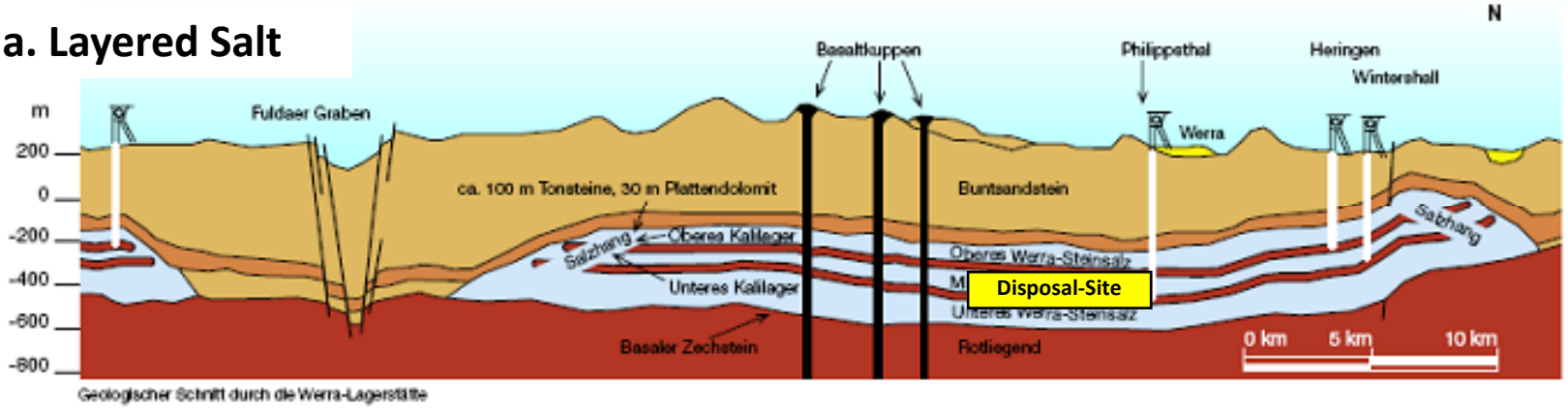
Enables complete inclusion
of waste disposed off

Waste Isolation Multibarrier System



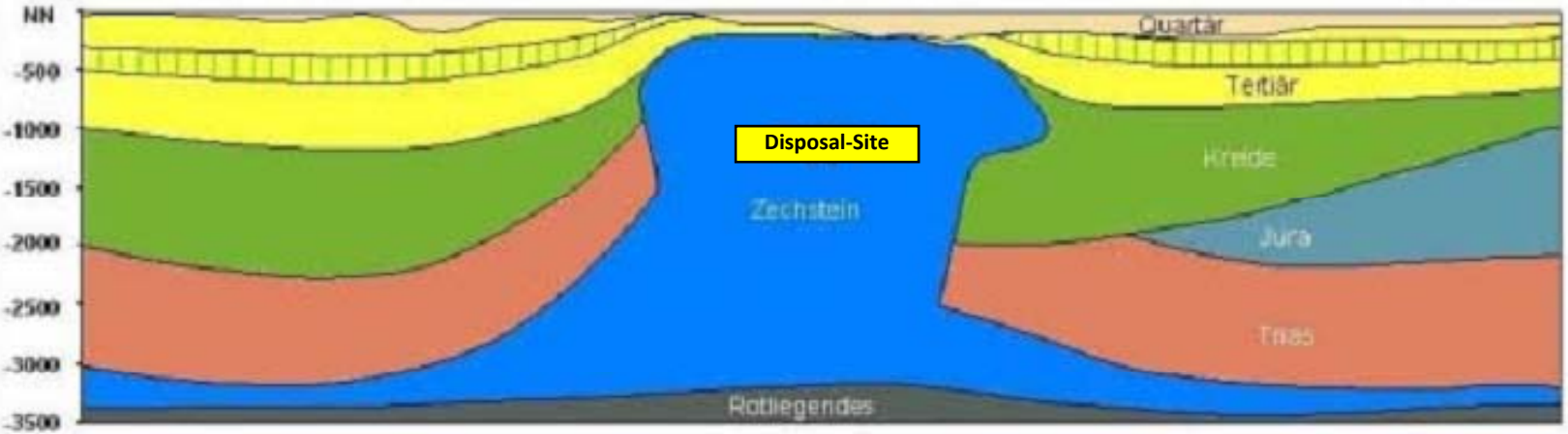
Concept of Underground Disposal in Salt Rock

a. Layered Salt

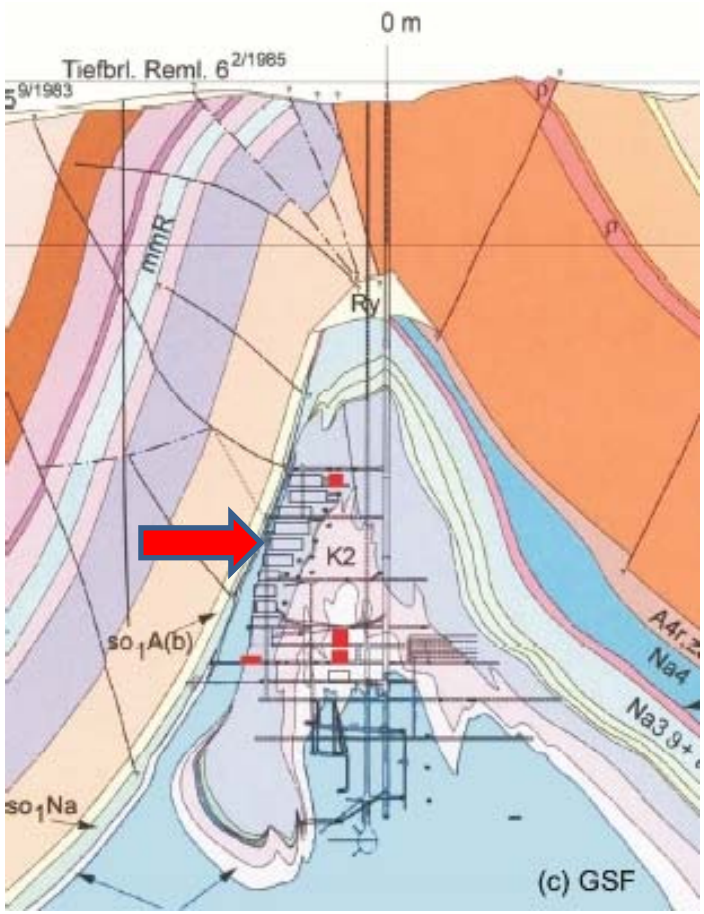


Geologischer Schnitt durch die Werra-Lagerstätte

b. Salt Dome



Concept of Underground Disposal in Salt Rock



Insertion: The „Asse-Case“

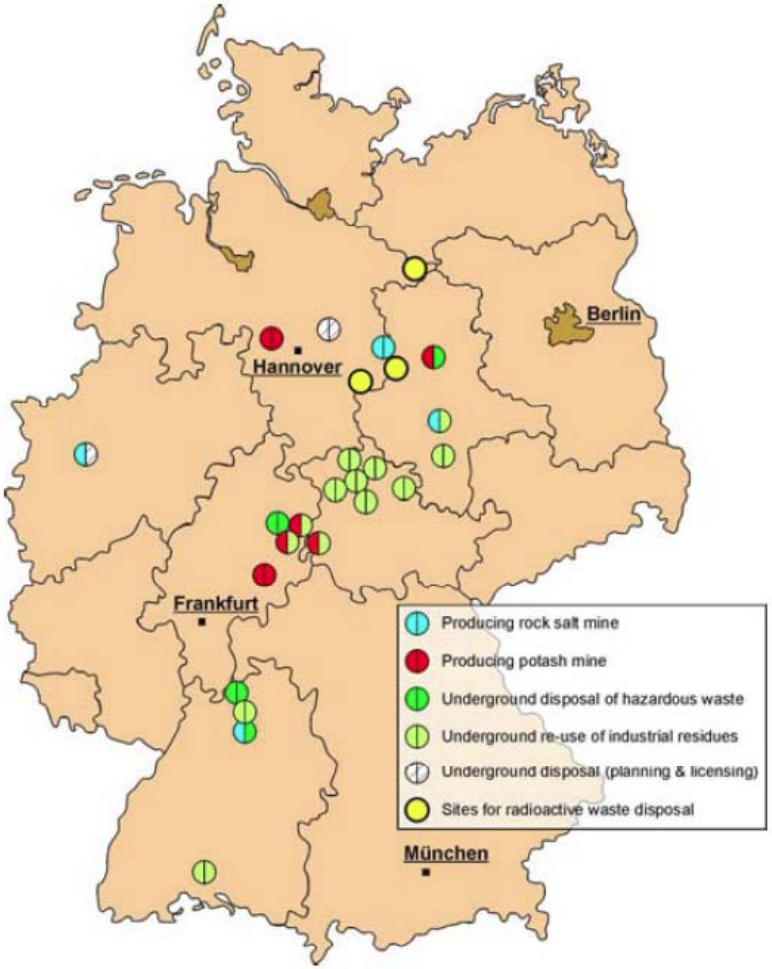
Main features:

- Old mine openings at the edge of salt dome
- Isolating Rock Zone not fully qualified

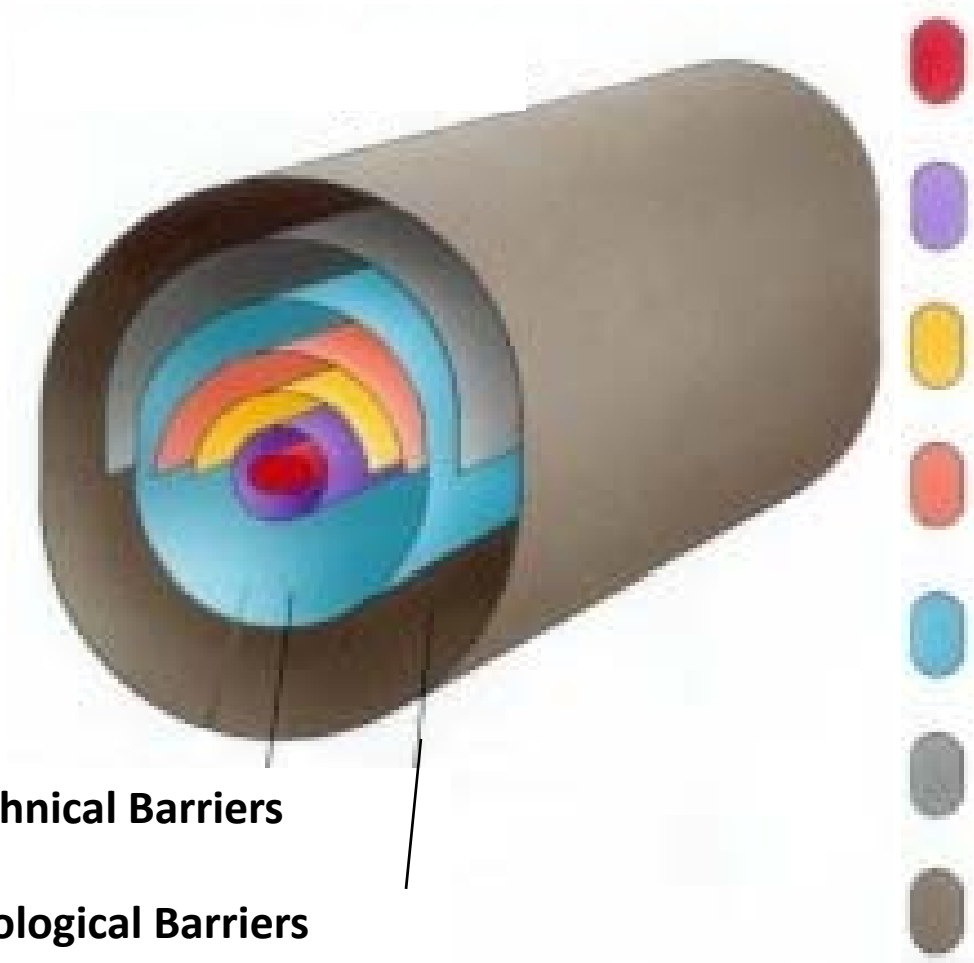
Types of Geosystems - Rock Salt & Clay(stone)

Geosystem		Thickness of host rock body	Potential disposal depth
Host rock	**Variant**		
Rock salt	Salt dome	up to > 1,000 m	800 m
Rock salt	Layered salt	app. 100 m	650 – 1,100 m
Clay / Claystone		up to 400 m	400 – 500 m
Rocks under clay cover		app. 100 m	500 – 1,000 m

Underground Disposal Sites in Salt Rock (Germany)



Waste Isolation Multibarrier System (1)



Technical Barriers

Geological Barriers

Waste content

Waste form

Canister

Backfill

Sealing

Host rock

Overburden

Whole system of multiple barriers must fulfill the requirements!

General Storage Conditions (1)

Not acceptable wastes for underground disposal*)

- Explosive
- Self inflammable
- Spontaneous combustible
- Infectious
- Radioactive
- Releasing hazardous gases
- Liquid
- Increasing their volume

*) acc. to current regulations, exemplary: Herfa-Neurode, operated by K+S

General Storage Conditions (2)

Prerequisites for underground waste disposal*)

- Waste storage only in disused, excavated areas of the mine
- Storage area has to be remote from extraction area with possibility to be sealed off from it
- Cavities remain open and have no backfill obligation
- Cavities have to be stable and must remain accessible even after prolonged time
- Mine has to be dry and free of water
- Storage areas have to be sealed off from water-bearing layers

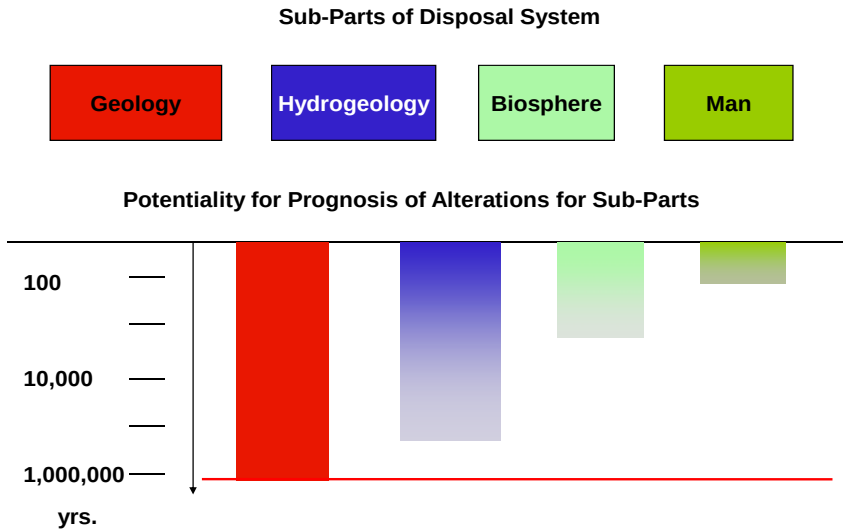
*) acc. to current regulations, exemplary: Herfa-Neurode, operated by K+S

Minimum Requirements acc. to Actual BIPRO-Report (2010)

Permanent Underground Storage	Temporary Underground Storage	Temporary Above Ground Facilities
Protection of GW against Hg	Protection of GW against Hg	Reversibility
Prevention of vapour emissions of Hg	Prevention of vapour emissions of Hg	Protection of Hg against meteoric water
Impermeability to gas and liquids of the surroundings	Impermeability to gas and liquids of the surroundings	Impermeability towards soils
Firmly encapsulating the wastes at the end of mines deformation process	Reversibility/retrievability	Prevention of vapour emissions of Hg

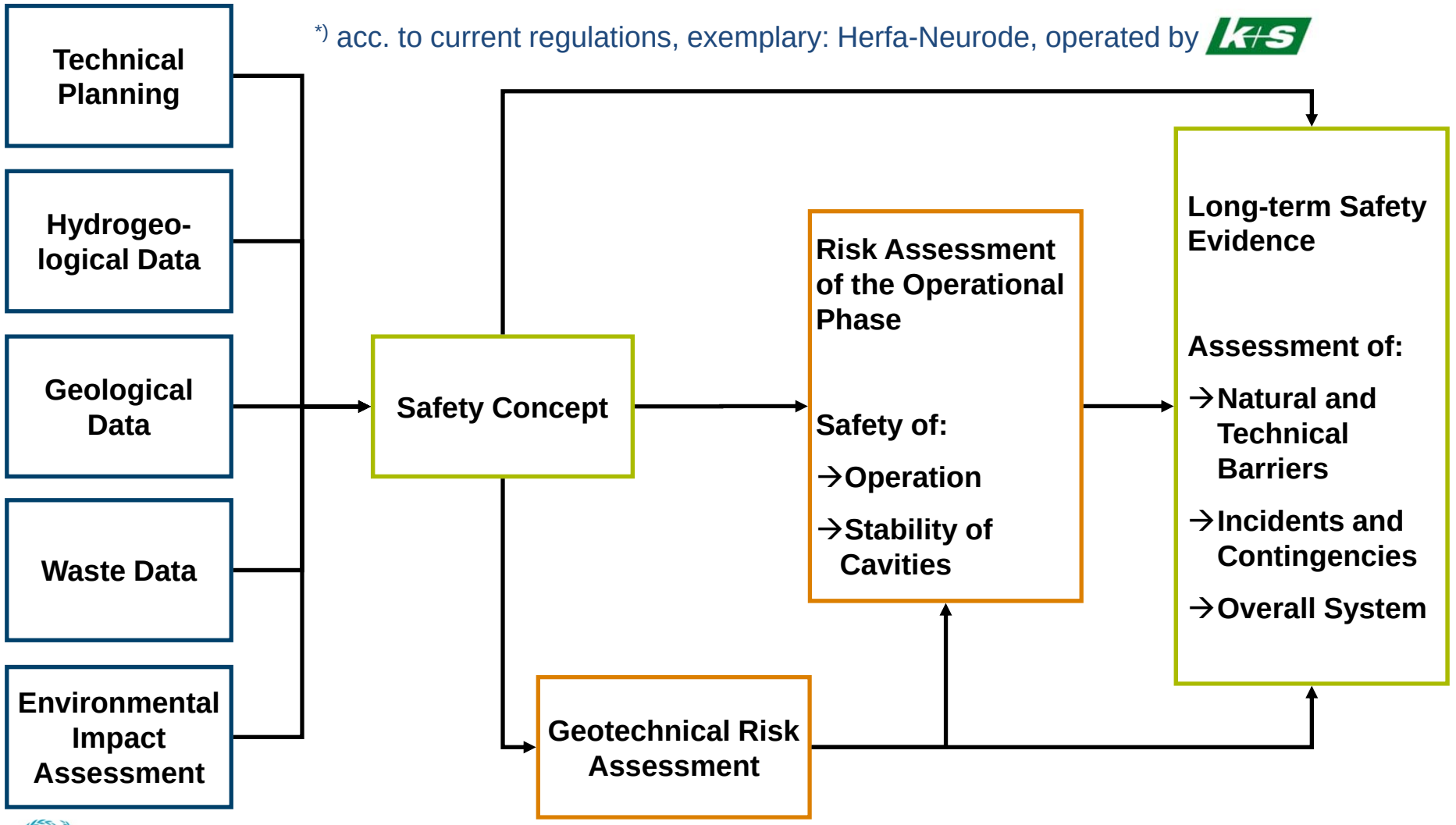
Strategy of Long-term Safety Assessment

- Geo-scientific long-term prognosis on site development
- Knowledge of site characteristics
  - Rocks and their properties
  - Hydrology (regional/local)
  - Hydrogeology
  - Biosphere
- Design of disposal facility
- Running off processes



Specific safety assessment*)

*) acc. to current regulations, exemplary: Herfa-Neurode, operated by K+S



Stabilization of Mercury and Mercury-Containing Waste

- Goal of stabilization
  - Conversion into a thermodynamically more stable solid form with
    - less volatility
    - less solubility
- Waste may be handled and stored with lower risk to
  - Human health
  - Environment

Stabilization Goal & Approaches

- Conversion into a thermodynamically more stable solid form
- Conversion into sulphide or selenide
  - By addition of sulfur → Cinnabar (HgS)
  - or selenium → HgSe
- Amalgamation (alloy with Hg)
  - By addition of metal powders (e.g. zink, copper)
- Stabilization in an insoluble matrix
  - Calcium silicate cement
  - Magnesia cement (Sorel)
  - Phosphate matrix

Handling Sequence at Herfa-Neurode

Receiving

Shaft loa

Drift trans

Disposa

Sealing of a chamber

Outlook

- Metallic mercury is chemically stable under conditions of a salt deposit
- High requirements on handling and ventilation due to vapor pressure
- Solubility of Hg(I) low, but significant changes due to impurities
- Solidification / stabilization feasible; benefit depends on impurities (type & quantity)

Demand of Regulations

- Which of the existing criteria are likely to be unsuitable for liquid Hg ?
- Which specific provisions for the containment are necessary and how does it effect the system ?
- EU: Specific criteria for underground disposal of liquid Hg currently under development

Annex

- Regulations (EU)
- Regulations (DE)
- Actual GRS-Reports
- Further Reports of Interest
- Contact

köszönöm תודה! děkuji

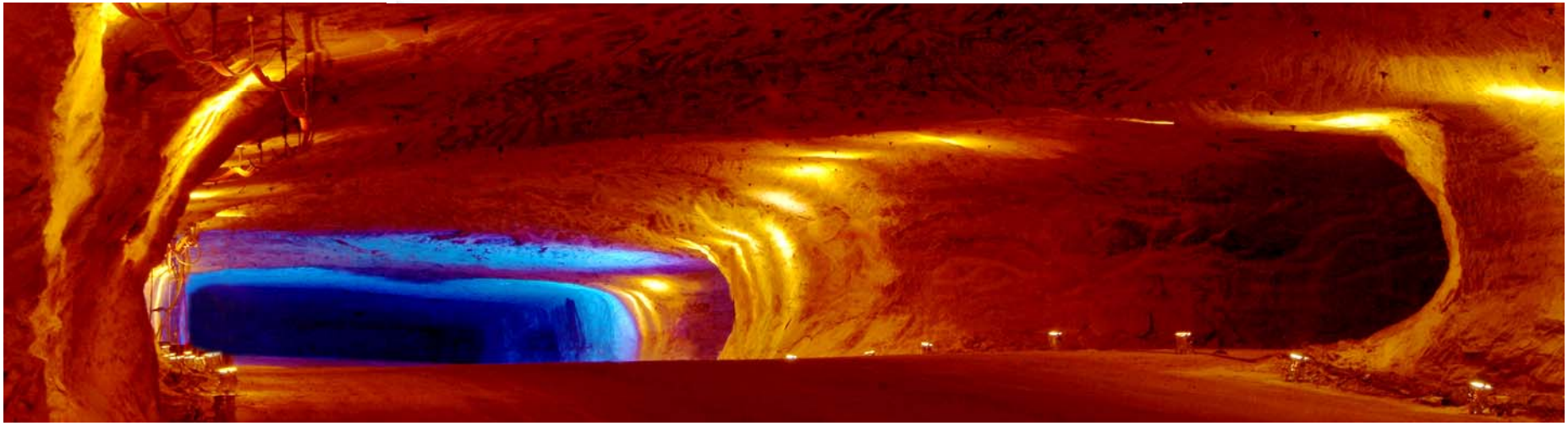
mahalo 고맙습니다

thank you

merci 谢谢 danke

Ευχαριστώ شكرا

どうもありがとう gracias



Regulations - EU

- Regulation (EC) No 1102/2008 of the European Parliament and of the Council of 22 October 2008 on the banning of exports of metallic mercury and certain mercury compounds and mixtures and the safe storage of metallic mercury – Download: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:304:0075:0079:EN:PDF
- Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste – Download: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:1999:182:0001:0019:EN:PDF
- 2003/33/EC: Council Decision of 19 December 2002 establishing criteria and procedures for the acceptance of waste at landfills pursuant to Article 16 of and Annex II to Directive 1999/31/EC – Download: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2003:011:0027:0049:EN:PDF

Regulations - DE

- Act for Promoting Closed Substance Cycle Waste Management and Ensuring Environmentally Compatible Waste Disposal, Sep 27th, 1994; last revision: Aug 11th, 2009 – Download (English version, as of Dec 9th, 2006): http://www.bmu.de/files/pdfs/allgemein/application/pdf/promoting.pdf (German, newest version): http://bundesrecht.juris.de/bundesrecht/krw-_abfg/gesamt.pdf
- Ordinance on Landfill Sites and Long-Term Storage Facilities (Landfill Ordinance – DepV) - Annex 2: Requirements with regard to the location, geological barrier, long-term safety records and closures measures for class IV landfill sites in salt rock, Apr 27th, 2009 – Download (English version): http://www.bmu.de/files/pdfs/allgemein/application/pdf/ordinance_simplifiying_landfill_law.pdf (German version): http://bundesrecht.juris.de/bundesrecht/depv_2009/gesamt.pdf

Actual GRS-Reports on Mercury

- Brasser, T. et al. (2008): Endlagerung wärmeentwickelnder radioaktiver Abfälle in Deutschland (Final disposal of heat-generating radioactive wastes in Germany). – GRS-247. Download: http://www.grs.de/module/layout_upload/index.html [covers also general aspects of underground disposal concepts, e.g. safety-philosophy, long-term safety, technical aspects]
- Hagemann, S. (2009): Technologies for the stabilization of elemental mercury and mercury-containing wastes. – GRS-252. Download: http://www.grs.de/module/layout_upload/grs_252_stabmerc.pdf
- Uram, E. et al. (2009): Market analysis of some mercury-containing products and their mercury-free alternatives in selected regions. – GRS-253. Download: http://www.grs.de/module/layout_upload/grs_253_markanal.pdf
- REMCOSITE: Remediation of Mercury Contaminated Sites. – Proc. Sino-German Workshop, Guiyang, May 27-30, 2008. Download: http://www.grs.de/module/layout_upload/remcosite_proc_2008.pdf
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Further Reports of Interest

- BIPRO (2010): Requirements for facilities and acceptance criteria for the disposal of metallic mercury. – Download: http://www.bipro.de/mercury/docs/Revised-final-report_Requirements-for-facilities-and-acceptance-criteria-for-the-disposal-of-metallic-mercury_100224.pdf
- COWI (2008): Options for reducing mercury use in products and applications, and the fate of mercury already circulating in society. – Download: http://ec.europa.eu/environment/chemicals/mercury/pdf/study_report2008.pdf