Metallic Mercury Long-Term Storage Possibilities / Options

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GRS

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**
  - Occupies <10 acres of land
  - Modular construction
  - Could be a series of smaller buildings

- **Underground Disposal**

- **Deep Injection**

  + Additional Option: Stabilization

- **Not considered:** Surface Landfill

*UNEP Global Mercury Partnership, Waste Management - Tokyo, Japan, March 09-10, 2010*
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\(^{\text{I})}\) or in
  - Deep underground hard rock formations\(^{\text{II})}\)

\(^{\text{I})}\) adapted for the disposal of metallic mercury
\(^{\text{II})}\) providing a level of safety and confinement equivalent to that of salt mines
## Host Rock Properties – Comparison

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

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Crystalline Rock - Features

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

Disposal

several kilometres
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

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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

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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

Former drift in a salt mine

Enables complete inclusion of waste disposed off
Waste Isolation Multibarrier System

Overburden

Shaft sealing

Drift sealing

Borehole sealing

Host rock

Waste & Canister

Backfill

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Concept of Underground Disposal in Salt Rock

a. Layered Salt

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)

<table>
<thead>
<tr>
<th>Geosystem</th>
<th>Thickness of host rock body</th>
<th>Potential disposal depth</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Host rock</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rock salt</td>
<td>Salt dome</td>
<td>up to &gt; 1,000 m</td>
</tr>
<tr>
<td>Rock salt</td>
<td>Layered salt</td>
<td>app. 100 m</td>
</tr>
<tr>
<td>Clay / Claystone</td>
<td></td>
<td>up to 400 m</td>
</tr>
<tr>
<td>Rocks under clay cover</td>
<td></td>
<td>app. 100 m</td>
</tr>
</tbody>
</table>
Underground Disposal Sites in Salt Rock (Germany)
Waste Isolation Multibarrier System (1)

- Waste content
- Waste form
- Canister
- Backfill
- Sealing
- Host rock
- Overburden

Whole system of multiple barriers must fulfill the requirements!

Technical Barriers

Geological Barriers

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

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

Sub-Parts of Disposal System

- Geology
- Hydrogeology
- Biosphere
- Man

Potentiality for Prognosis of Alterations for Sub-Parts

- 100
- 10,000
- 1,000,000 yrs.
Specific safety assessment

Technical Planning

Hydrogeological Data

Geological Data

Waste Data

Environmental Impact Assessment

Safety Concept

Risk Assessment of the Operational Phase

Safety of:
- Operation
- Stability of Cavities

Geotechnical Risk Assessment

Long-term Safety Evidence

Assessment of:
- Natural and Technical Barriers
- Incidents and Contingencies
- Overall System

*) 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 loading
- Drift transport
- Disposal in a chamber
- Sealing of a chamber

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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(l) 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
thank you

merci

謝谢

danke

شكرا

どうもありがとうございます

gracias
Regulations - EU


Regulations - DE

  (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):
  (German version): http://bundesrecht.juris.de/bundesrecht/depv_2009/gesamt.pdf
Actual GRS-Reports on Mercury


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Further Reports of Interest
