Methodological Approaches to Safe Waste Disposal in Rock Salt Formations

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Objectives and contents of long term safety analyses for disposal in rock salt

- In Germany, a stepwise and criteria-based site selection procedure is stipulated by law.
- In this context, preliminary long-term safety analyses are an essential element for the stepwise assessment of the results of above-ground and underground explorations in a site selection procedure.
- The technical accuracy and the reliability of the results depend on the state of knowledge (site situation, safety relevant processes etc.) obtained at the respective step.
  Therefore: Preliminary safety analyses
- The methodologies and contents of preliminary safety analysis are shown in the following by using the example of the research project **Preliminary Safety Analysis Gorleben (VSG)**.

Exploration history of the Gorleben salt rock site

- April 1979: Beginning of the above-ground site investigations at Gorleben.
- July 1883: Approval for the subsurface exploration by the federal government.
- 1986 – 2000: Beginning of the subsurface exploration area, shaft constructions, opening of exploration area in 840 m depth.

- June 2000: Exploration stop (moratorium); reason: need for clarification of generic safety-related and conceptual question related to geologic disposal.
- October 2010: Resumption of subsurface exploration.
- November 2012: Exploration stop to avoid a preference of the Gorleben site towards other sites to be selected in future.

➢ **Up to now, around 15 % of the area needed for a drift disposal of all heat-generating waste are investigated.**

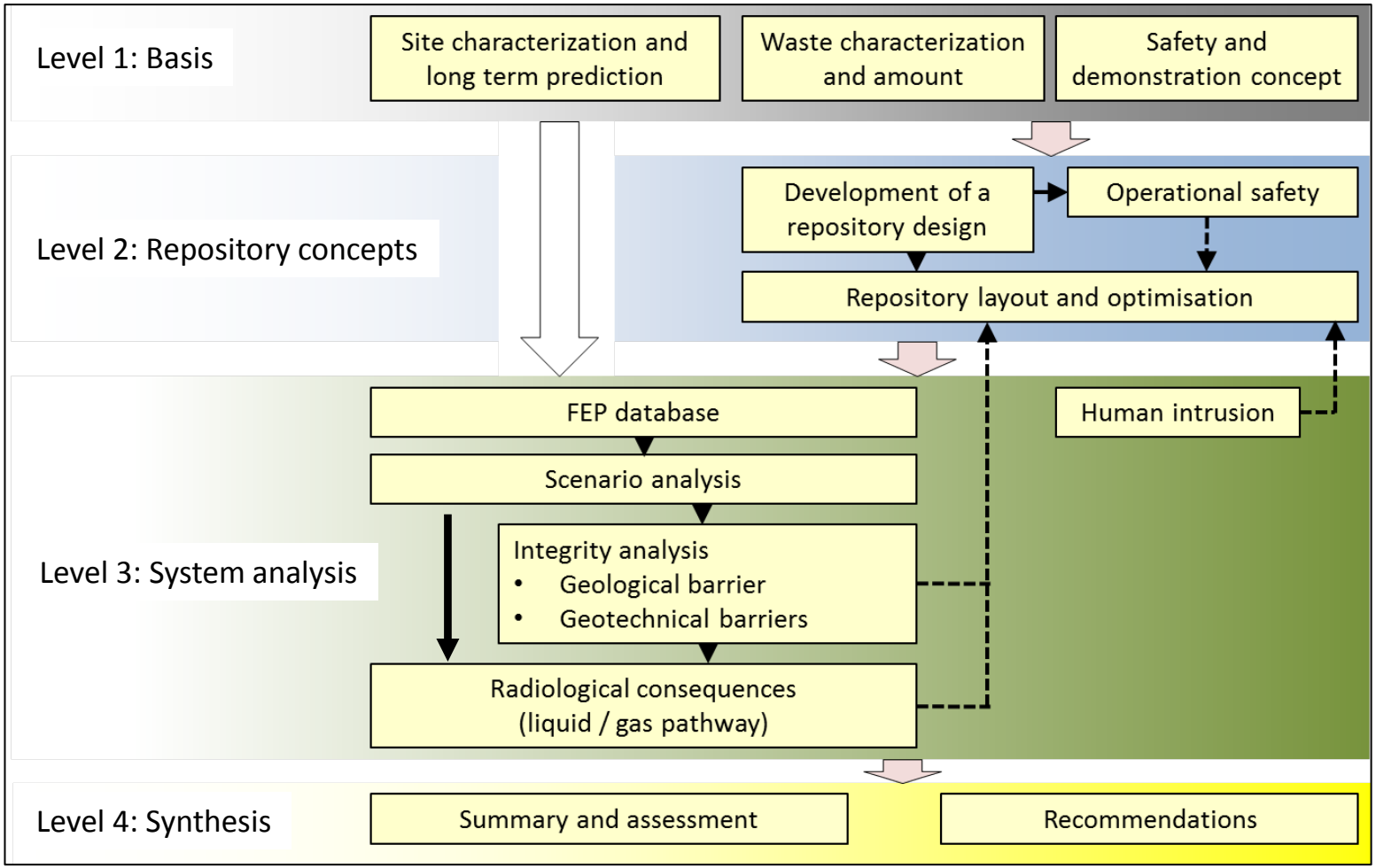
Objectives of the VSG

Term: July 2010 – March 2013

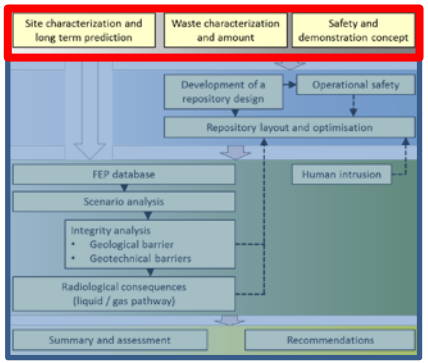
- Compilation and assessment of the results obtained so far from the exploration of the Gorleben salt dome and from disposal research in rock salt
- Further development of repository concepts for rock salt sites
- Conduction of a prototypic safety analysis with the focus on long-term safety, based on today‘s state of knowledge on safety-relevant processes and the Gorleben site.
- Assessment of the analysis results by comparing them with the Safety Requirements of the Federal Ministry for Environment, Reactor Safety and Nature Conservation (BMU)
- Identification of R&D needs regarding disposal at salt rock sites
- Assessment of the adaptability of the VSG methodology for site selection procedures

Partners / Concept of the project

80 scientists/ 9 institutions:

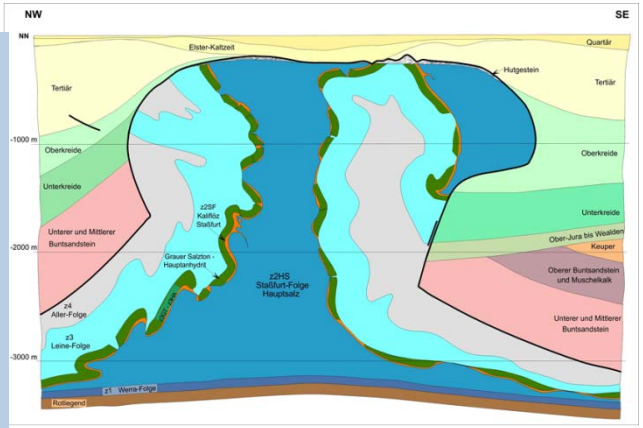


Level 1 Basis: Geoscientific site description and long-term prognosis



Compilation of the geoscientific information of the site

- Hydrogeology
- Overburden
- Salt structure
- Geotechnical studies



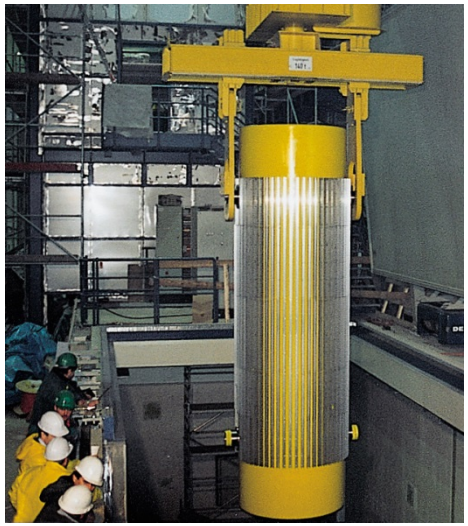
Prognosis of future site evolution:

- Tectonics
- Volcanism
- Salt movement
- Subrosion (dilution by groundwater)
- Climatic events (e.g. glaciation)
- etc.

Level 1 Basis: Waste volume and characteristics

Aim: compilation of the volume and characteristics of heat-generating radioactive waste in Germany:

1. **Spent fuel assemblies**
2. **Waste from earlier reprocessing**
3. **Waste from research and prototype reactors**



Basis for the development of the repository concepts: Waste volumes on basis of phase-out decision of June 2011

Image source: GNS

Level 1 Basis: Safety concept and concept of compliance demonstration

Safety concept:
Specification of the BMU Safety Requirements for salt rock sites

Description of the measures for achieving a safe containment of the waste

Concept of compliance demonstration:
Specification of the safety verification concept according to the BMU‘s Safety Requirements for salt rock sites

Uncertainties:
Concepts for handling uncertainties and scientific knowledge gaps

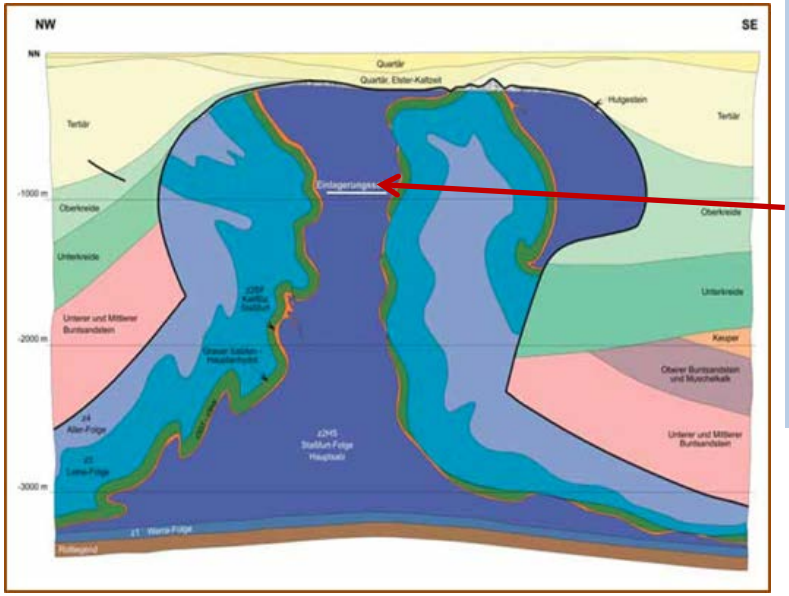
Level 1 Basis: Safety and demonstration concept: Main assessment criteria

- Assessment basis for VSG: Safety Requirements of the BMU, Sept. 2010

- There has to be a sufficiently extensive containment-providing rock zone (CPRZ) whose integrity (preservation of the safety-relevant properties) can be demonstrated over a period of 1 million years.

- A robust and maintenance-free staggered barrier system made up of technical components (seals + backfill) has to be developed, which will ensure, in coaction with the geological barrier, that there will be no inadmissible releases of radionuclides.
  This also applies in the case that an individual barrier fails to be fully effective.

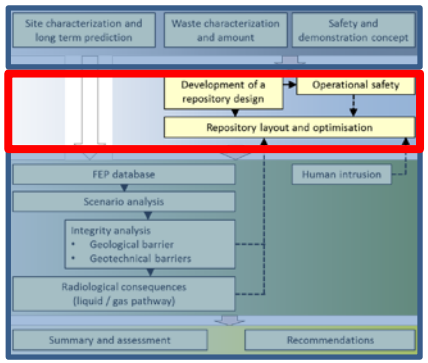
Level 1 Basis: Safety concept (barrier concept)



- **Geological barrier:**
  - Hauptsalz (rock salt) of the Staßfurt series, surrounding the repository mine = containment-providing rock zone (CPRZ) in a depth of 870 m
  - 50 m safety margin to rock types outside the Hauptsalz (z2)

- **Long-lasting geotechnical barrier:**
  „Long-term sealing“: salt grit backfill, time needed for the development of the barrier effect (compaction) depends i.a. on temperature and humidity
- **Fast-acting temporary geotechnical barriers:**
  - Shaft seals: multi-layer system (seals, abutments, storages, filters)
  - Infrastructure areas: storage element (non-compactible backfill: crushed rock)
  - Drift seals: seal-abutment systems (Sorel concrete)

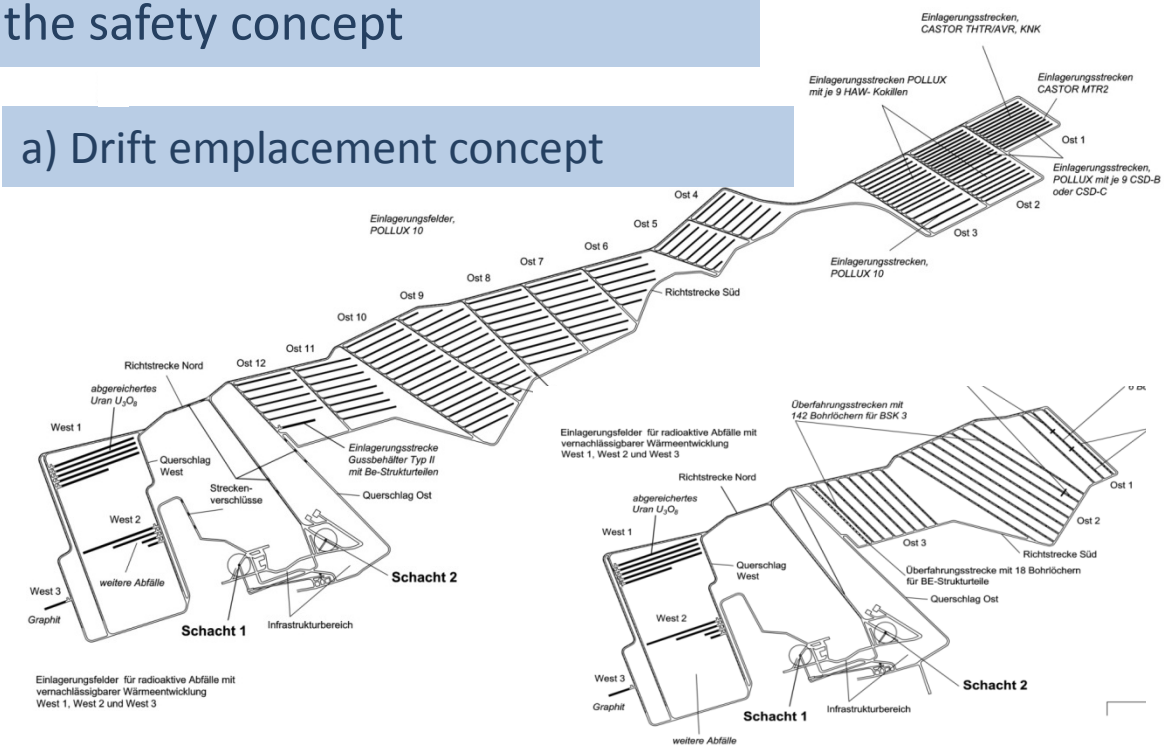
Level 2 Repository concepts



Aim: Designing and optimisation of repository mines for the volumes of waste arising with consideration of
- the given geological conditions
- and the safety concept

Aspects:
- Repository dimensions
- Technical installations and casks
- Emplacement operation
- Operational safety
- Retrievability during the operational phase
- Closure concept

a) Drift emplacement concept



b) Borehole emplacement concept

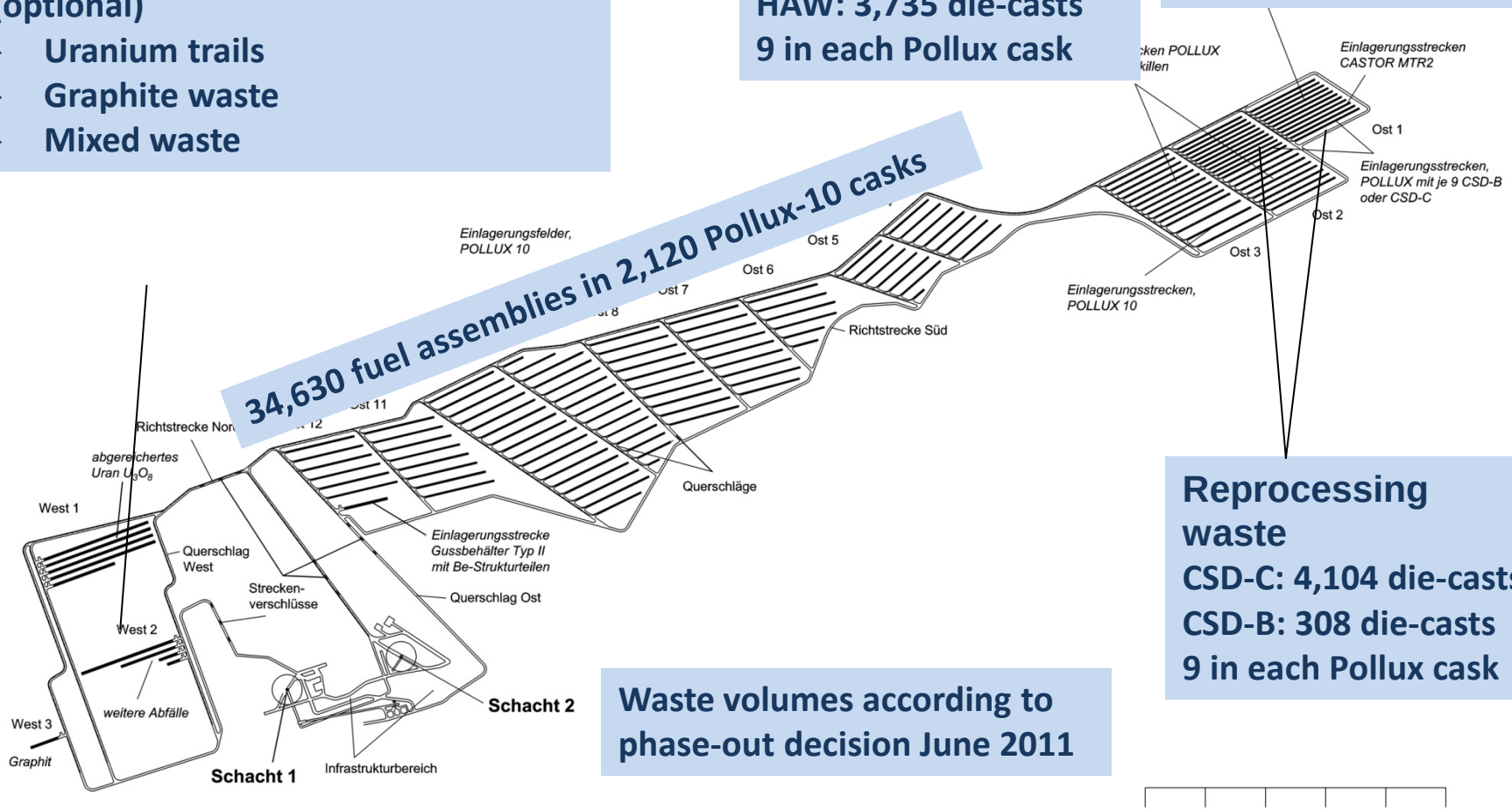
Level 2 Repository concepts: Drift emplacement design

Waste with negligible heat generation (optional)
- Uranium trails
- Graphite waste
- Mixed waste

Reprocessing waste
HAW: 3,735 die-casts
9 in each Pollux cask

Waste from research and prototype reactors
511 Castor casks (AVR/THTR/KNK/MTR)

34,630 fuel assemblies in 2,120 Pollux-10 casks

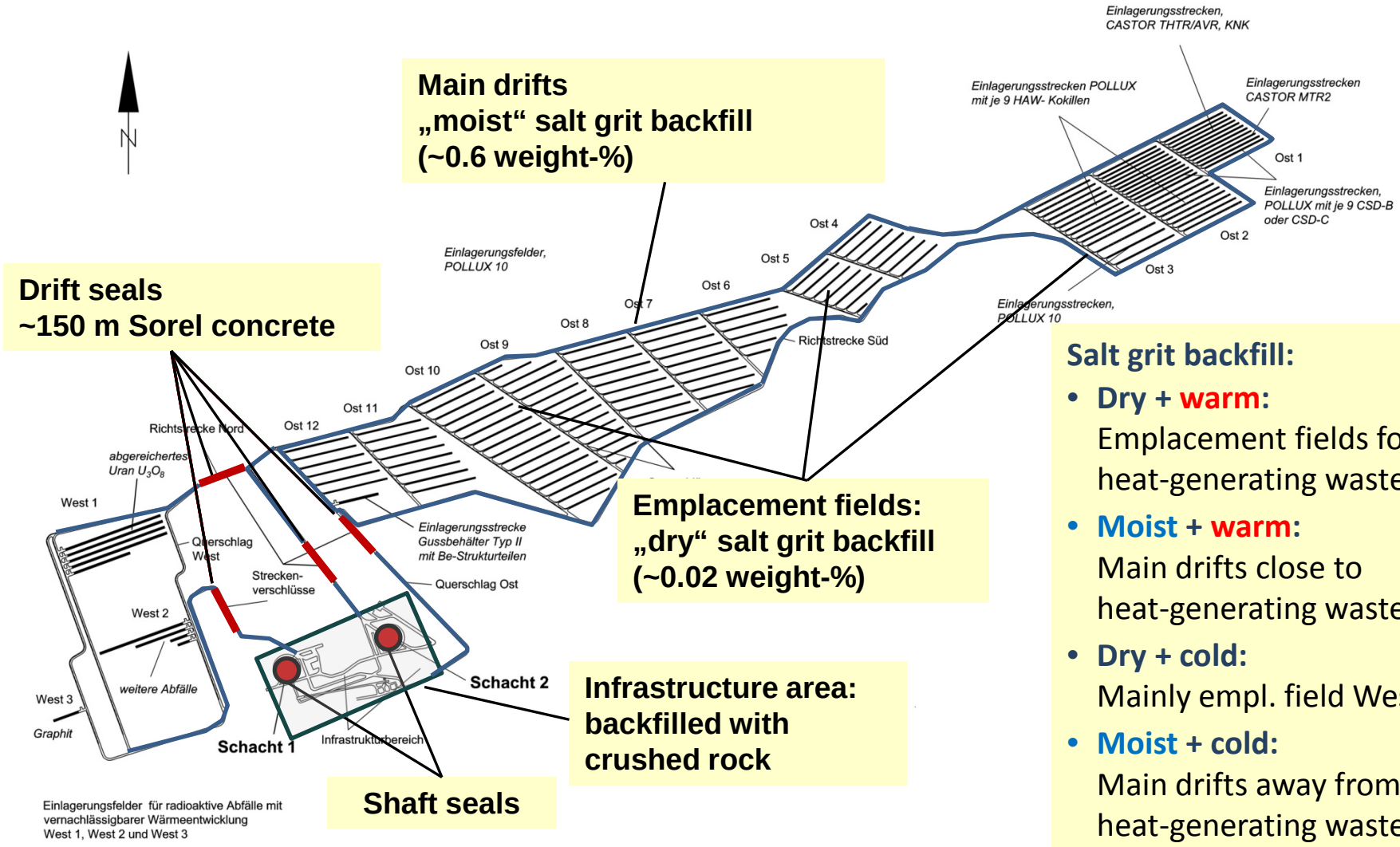


Einlagerungsfelder für radioaktive Abfälle mit vernachlässigbarer Wärmeentwicklung West 1, West 2 und West 3

Waste volumes according to phase-out decision June 2011

Reprocessing waste
CSD-C: 4,104 die-casts
CSD-B: 308 die-casts
9 in each Pollux cask

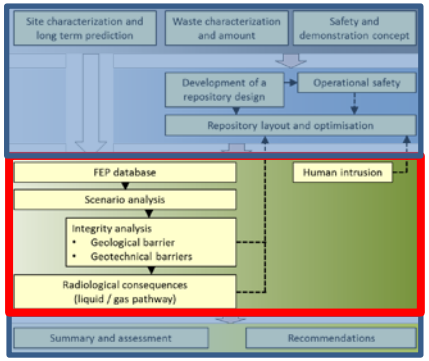
Level 2 Closure concept: Drift emplacement design



Salt grit backfill:

- **Dry + warm:**
  Emplacement fields for heat-generating waste
- **Moist + warm:**
  Main drifts close to heat-generating waste
- **Dry + cold:**
  Mainly empl. field West
- **Moist + cold:**
  Main drifts away from heat-generating waste

Level 3 System analysis: FEP catalogue and scenario development



- **FEP: Features, Events, Processes:**
- Components for scenario development
- 115 FEPs (geology, climate, operation, waste, repository) for site and repository concept
- Characteristics:
  - probability of occurrence
  - dependencies: initiating / influencing / resulting / influenced FEPs
  - impact on barriers
- Documentation in a catalogue of FEPs

Scenario development (derivation of possible repository system evolution scenarios)

Reference scenarios (1/concept)
- probable evolution

Alternative scenarios
- less probable evolutions (e.g. increased permeability of shaft or drift seals)

Level 3 System analysis: Integrity analysis

Thermo-mechanical and hydraulic calculations:

- Load cases: Heat generation of the waste, climatic impacts (cold periods), gas pressure generation of the waste, etc.
- Verification of the integrity criteria for the geological barrier (Safety Requirements of the BMU):

  – **Dilatancy criterion:**
  Temperature induced stress **<** rock-specific dilatancy limit
  ➔ avoidance of micro cracks

  – **Fluid pressure criterion**:
  Minimal principal rock stress **>** hydrostatic pressure at this depth
  ➔ avoidance of pathways for fluids (liquid and/or gas)

Level 3 System analysis: Integrity analysis, results (1)

1. Thermo-mechanical calculations:

- Dilatancy and fluid pressure criteria are occasionally not fulfilled at the top of the salt dome (salt surface) due to the temperature induced stress.
- Below, up to the level of the emplacement floor, there remains host rock with several 100 m thickness without any loss of intergity.
- The thermal criteria for temperature-sensitive salts (carnallitite) are fulfilled.

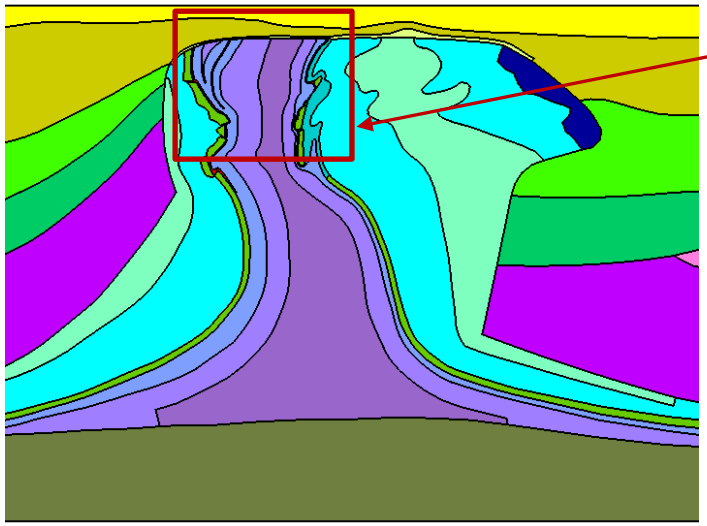
2. Hydraulic calculations:

- Fluid pressure (gas) < lithostatic rock stress, exception: temporary excavation-damaged zone around cavities.

➔ Integrity is maintained in wide areas around the repository.

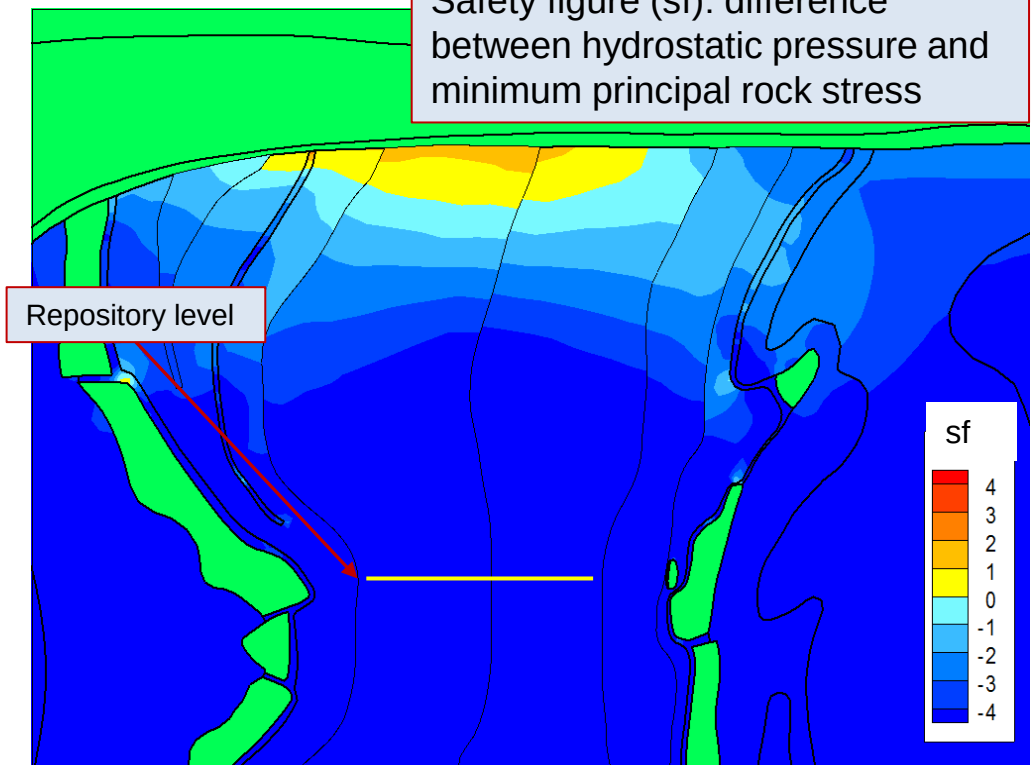
➔ No loss of integrity inside the containment-providing rock zone (50 m Hauptsalz, surrounding the repository).

Level 3 System analysis: Integrity analysis, results (2)



Temperature induced stress

Safety figure (sf): difference between hydrostatic pressure and minimum principal rock stress



Max. transgression of the minimum stress criterion (safety figures yellow – red, BGR calculations) in the salt structure, approx. 30 years after instantaneous emplacement

Level 3 System analysis: Radiological consequence analysis, results (1)

Reference scenarios:

- Even at low salt grit compaction velocities there is no entry of ***external solutions*** to the emplacement areas:
  - ➔ sufficient hydraulic resistance of the intact shaft seals

- Very small ***internal solution*** amounts in the emplacement areas (backfill moisture 0.02 weight-% + moisture content in the casks):
  - ➔ Neither complete corrosion of the casks nor any significant corrosion gas formation (hydrogen)

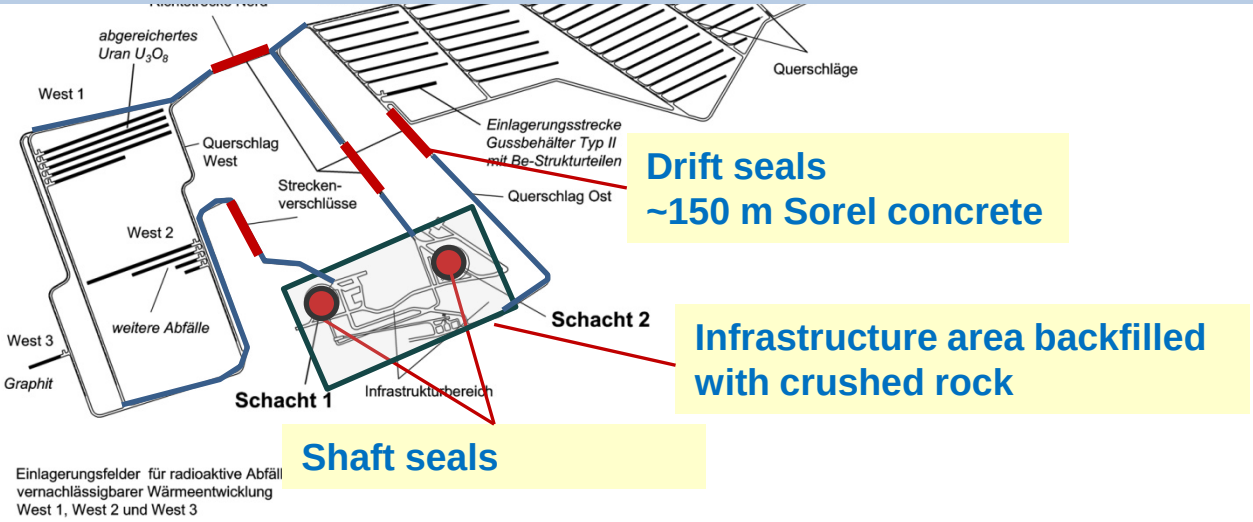
- ***Dissolved radionuclides:*** No release via the drift seals

- ***Gaseous radionuclides:*** Clear R&D need for the release mechanisms (source terms), predominantly for those beeing instantly released from structural fuel assembly parts. There is also a potential for optimisation in future repository concepts (e.g. use of gas-tight casks for structural fuel assembly parts)

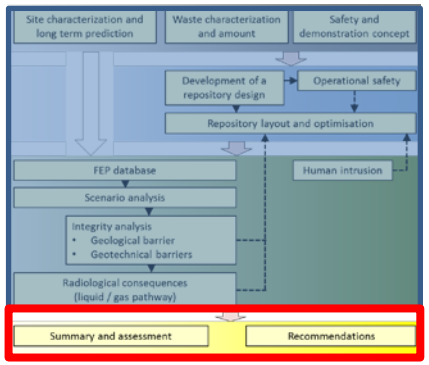
Level 3 System analysis: Consequence analysis, results (2)

- **Alternative scenario ("Shaft seal failure"):**
  Backfilling of the infrastructure area with crushed rock (approx. 100,000 m^3 pore space) prevents a fast hydraulic pressure increase at the shaft seals to a hydrostatic pressure over approx. 1,000 years („buffer storage effect").

  ➔ Sufficient time for the salt grit backfill to achieve adequate barrier properties through compaction (according to the recent knowledge → R&D need)



Level 4 Synthesis: Conclusions (1)



- One important result of the project VSG is a systematic identification of existing uncertainties leading to a comprehensive compilation of research and development needs (salt grit compaction, two phase flow, gaseous radionuclide source terms). In some cases assumptions had to be made to bridge knowledge gaps.

- As the exploration of the Gorleben site covers only a small part of the area needed for disposal, a general assumption had to be made, that the results obtained from the exploration area are also valid for to the whole area needed.

- On the basis of these assumptions, the containment capacity of the developed repository concepts in coaction with the geological barrier (as far as recently investigated) is expected to fulfill the safety related standards of the German Safety Requirements. This is also valid for rock salt sides with geological conditions comparable to the Gorleben side.

Level 4 Synthesis: Conclusions (2)

- The repository concepts, including the retrieval concept, are considered technically feasible. Some of the safety analyses required in the Safety Requirements of BMU can only be carried out after further specification of the technical planning.

- Preliminary safety analyses should be repeated periodically in order to sum up the state of the art of science and technology as well as to identify further R&D-needs.

- The methodology and the safety and demonstration concept can be applied to other salt rock sites; an application to clay stone salt is only possible to a limited extent.

The VSG Team:

Thank you very much for your attention!

VSG-Reports are available at:
http://www.grs.de/vorlaeufige-sicherheitsanalyse-gorleben-vsg