The German Geologic Repository

0. NAS-Report 1157 → pull ~~AOE~~
00. Long cooperation with AEC, OWI, ONWI, ORWM

1. Nuclear fuel cycle

Closing the back end of the nuclear fuel cycle in Germany is addressed by reprocessing spent nuclear fuel from German nuclear power plants.

Reprocessing takes place at Cogéma in La Hague, France, and at BNFL, Sellafield, UK.

Reprocessing results in different waste types:

Fut.: • Vitrified HLW (Heat output: ~2.5 kW)

• Solidified MLW (cemented hulls, fuel element structure materials, dissolver sludges). Drums and containers up to 1 m³ volume with heat generation of ~100 W/container.

2. Option: Direct disposal of spent fuel

Since about 10 years, an optional R&D-program is under-way to investigate the direct disposal of spent fuel elements without reprocessing.

The concept under consideration foresees

Fut.: the use of self-shielding heavy POLLUX-containers.

3. Repository for all categories of radioactive waste

In Germany, it was decided from the beginning (in the early sixties) to dispose of all types of radioactive wastes in an underground repository:

(2)

wastes.

- No differentiation between TRU-waste and non α-waste.
- Not only heat generating waste (vitrified HAW, spent fuel elements, specific MAW) but also non-heat generating LLW and ILW from reprocessing, nuclear power plants, industry, medical application, research will be disposed of in an underground repository

Folio 4. German concept for a HAW repository

3(4)(Folio) 5. Salt dome of Gorleben is being explorated

6. Different stratigraphy

In the US, different candidate sites in salt have been investigated:

- Permian Basin, Texas: Deaf Smith County
- Gulf Interior Region:
  - Richton Dome } Mississippi ~~Louisiana~~
  - Cypress Creek Dome }
  - Vacherie Dome, Louisiana
- Paradox Basin, Utah: Gibson Dome

Very deep mother beds: up to 10,000 meters

Pure rock salt

Stratigraphy of German Zechstein (Upper-Permian) is different:

Assoc. Band } Folio

- Occurrence of different evaporite strata:
  - Pelite or clay seams (Grauer Salzton, T3)
  - Anhydrite bands (Main Anhydrite, A3)
  - Rock salt (Halite): main mass

(3)

Folie

- Rock salt is not only pure halite NaCl, but may contain some other salt minerals:
  - Anhydrite $CaSO_4$
  - Polyhalite $K_2SO_4 \cdot MgSO_4 \cdot 2CaSO_4 \cdot H_2O$
  - Kieserite $MgSO_4 \cdot H_2O$
  - Carnallite $KCl \cdot MgCl_2 \cdot 6H_2O$

7. Thermal stability of salt minerals with crystal water

Some salt minerals with crystal water release part of this water being heated:

- Polyhalite is partially decomposed at temperatures above 230°C

Folie

- Carnallite is even more sensitive: Water release starts already at 85°C with no stress, but this temperature (threshold) increases up to ~145°C under repository conditions at a depth of about 800 m.

- Consequence:

Thermal limitations are required:

- About 200°C in Staßfurt rock salt which may contain some kieserite
- About 145°C within carnallite bed Staßfurt which can be achieved by proper safety distances between the HAW emplacement areas and the carnallite seam.

8. Internal structure of the Gorleben salt dome

In order to consider the site specific stratigraphic situation of the Gorleben salt

(4)

is necessary.

Folie Speculative geological situation at about 840 m depth based on present knowledge is shown in this overhead drawing.

9. Technical layout of the Gorleben repository

The technical layout of the repository has to take into consideration:

- Geometric situation of the salt dome
- Geological or stratigraphical situation
- Types of radioactive waste (all categories)
- Quantities of waste (planned lifetime 70 years for a nuclear capacity of 2500 GWe)

→ 1,000 HAW-canisters per year
23 POLLUX-casks per year
2,800 heat generating MAW-containers per year

→ 2,500 container (20,000 m³) per year
2,000 cast iron container (2,500 m³) -
2,000 concrete container (3,000 m³) -
} LLW+ILW (non heat generating)

Folie This leads to the planning of deep boreholes (300 - 600 m) for the emplacement of HAW canisters and MAW containers.

Non-heat generating wastes will be emplaced in special chambers.

Because of the dimensions (~6 m long, 1,5 m in Ø) and of weight (~65 tons), the POLLUX-containers can not be disposed of in deep vertical boreholes, but shall be disposed of by horizontal emplacement in properly designed drifts.

10. Thermo-mechanical problems

„Thermal loading" is not the real problem of a repository for heat-generating waste in a German salt dome like Gorleben.

Stemming from the performance of safety assessments, it is recognized that the thermo-mechanical behaviour of the repository during the operational and the post-operational phase is more important:

- Undue thermal stresses in anhydrite rocks, especially in the main anhydrite (A3) must be avoided. These could lead to the opening of joints originally closed and/or filled with secondary minerals, like e.g. rock salt, and thus to potential pathways for intruding groundwater (so-called „anhydrite scenario").
- Occurrence of undue tensile stresses at the contact of the salt dome with the surrounding rock must be avoided which theoretically could also lead to pathways.
- Intolerable uplift of the land surface above the repository (e.g. > 1 m with time) must be avoided.

In order to solve these thermo-mechanical problems, a thermo-mechanical consequence analysis must be performed.

11. Thermal problems

In addition to the thermo-mechanical issues

have to be regarded:

- Thermal load of carnallite above ~ 145°C must be avoided because of possible crystal water release at higher temperatures.
- Heating of groundwater flowing in the overburden rocks above the salt dome to more than a very few degrees Celsius (2-3) must be avoided.

12. In total, this means that numbers for the thermal loading of a HAW-repository can only be fixed by a complete thermal and thermo-mechanical analysis taking into account the site-specific geological and hydrogeological situation.

13. Available variable parameters

Available parameters which can be varied in order to regulate the thermal loading of the repository, are:

Fol.:
- Cooling time (i.e. interim storage) of HLW or spent fuel elements, respectively.
- Geometric layout of the repository
  - Depth and distance of HLW borehole.
  - Density of POLLUX-containers in drifts
  - Number of emplacement levels in the repository for POLLUX-containers
- Filling strategy
  - Continuous filling of one HLW-borehole
  - Simultaneous filling of several boreholes

(7) 14 Respective R&D-program

The respective R&D-program, which is under way since many years, consists of three main parts:

1. Modelling

Development of suitable thermal and thermo-mechanical computer models (ANSALT)

2. Laboratory program

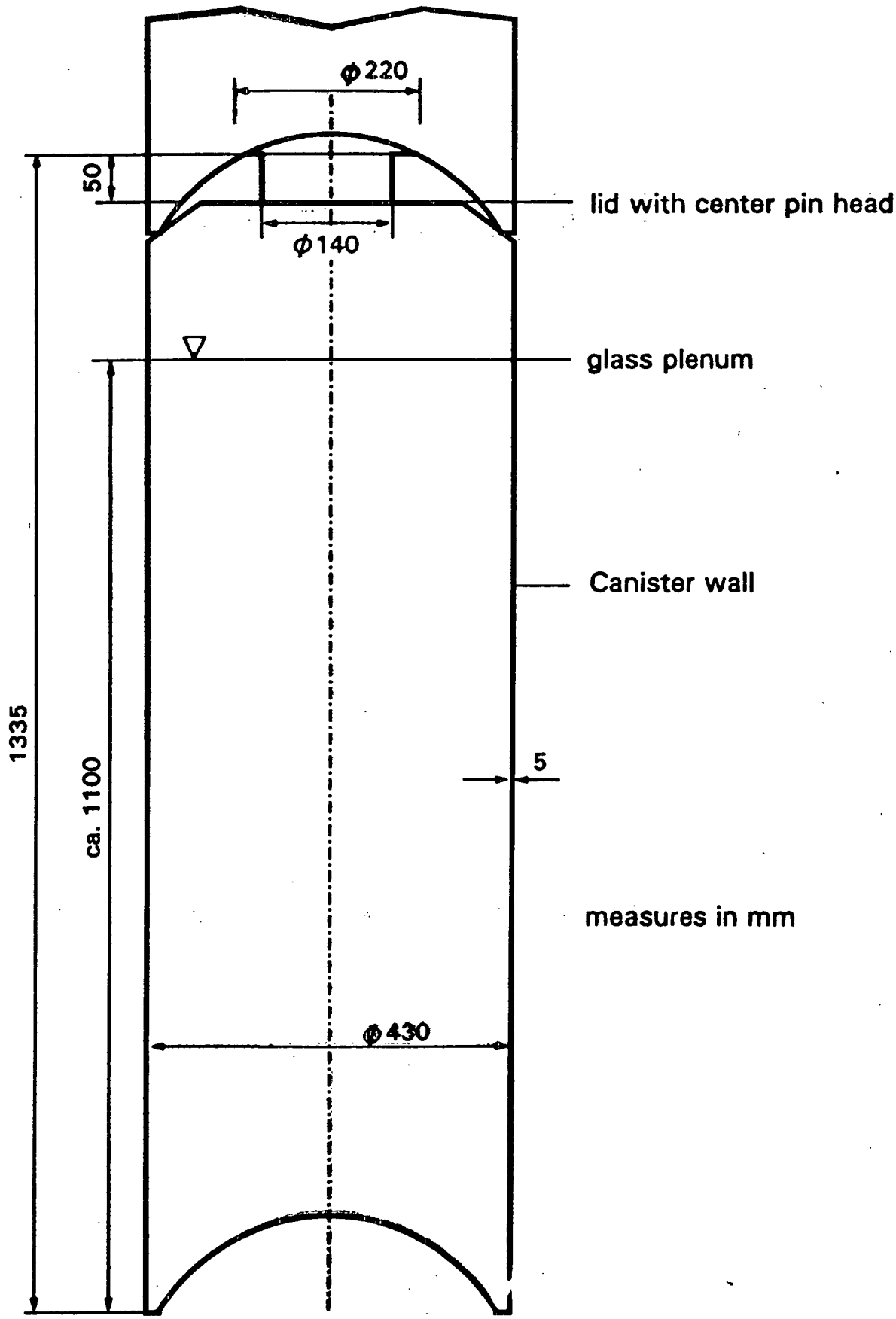
Identification of proper materials' data and development of appropriate constitutive laws.

3. In situ-tests

Many in situ tests were performed in the Asse salt mine:

- Rock mechanical measurements at ambient and at elevated temperatures
- Heater tests
- US-German „Drive Migration Test" with Co-60-sources
- 2 Folien · HAW Test Disposal (ready for operation!)
- Folie · TSS-experiment: thermal simulation of drift emplacement of POLLUX-containers
- Folie · MAW-test disposal

Container with vitrified HAW



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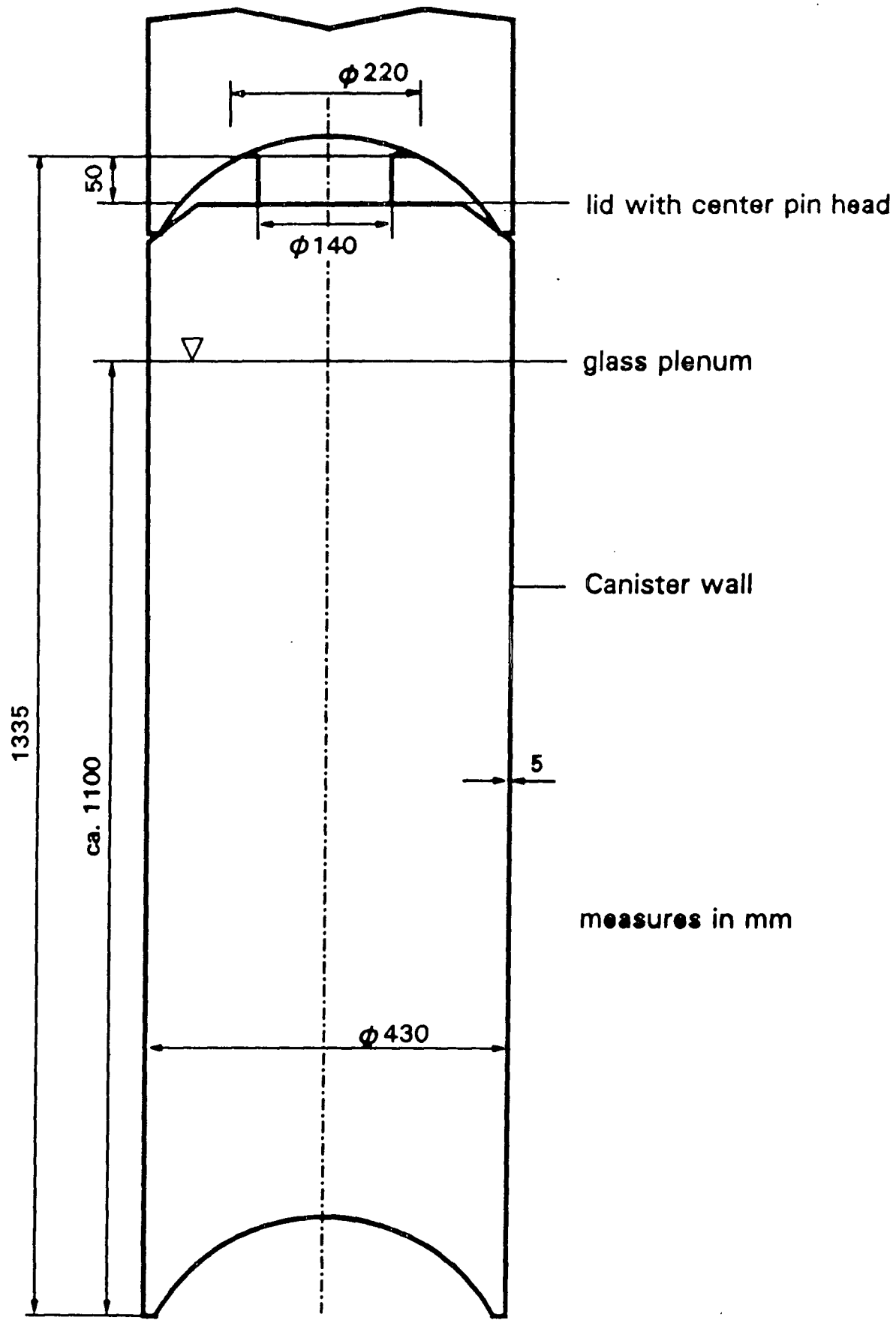
Container with vitrified HAW



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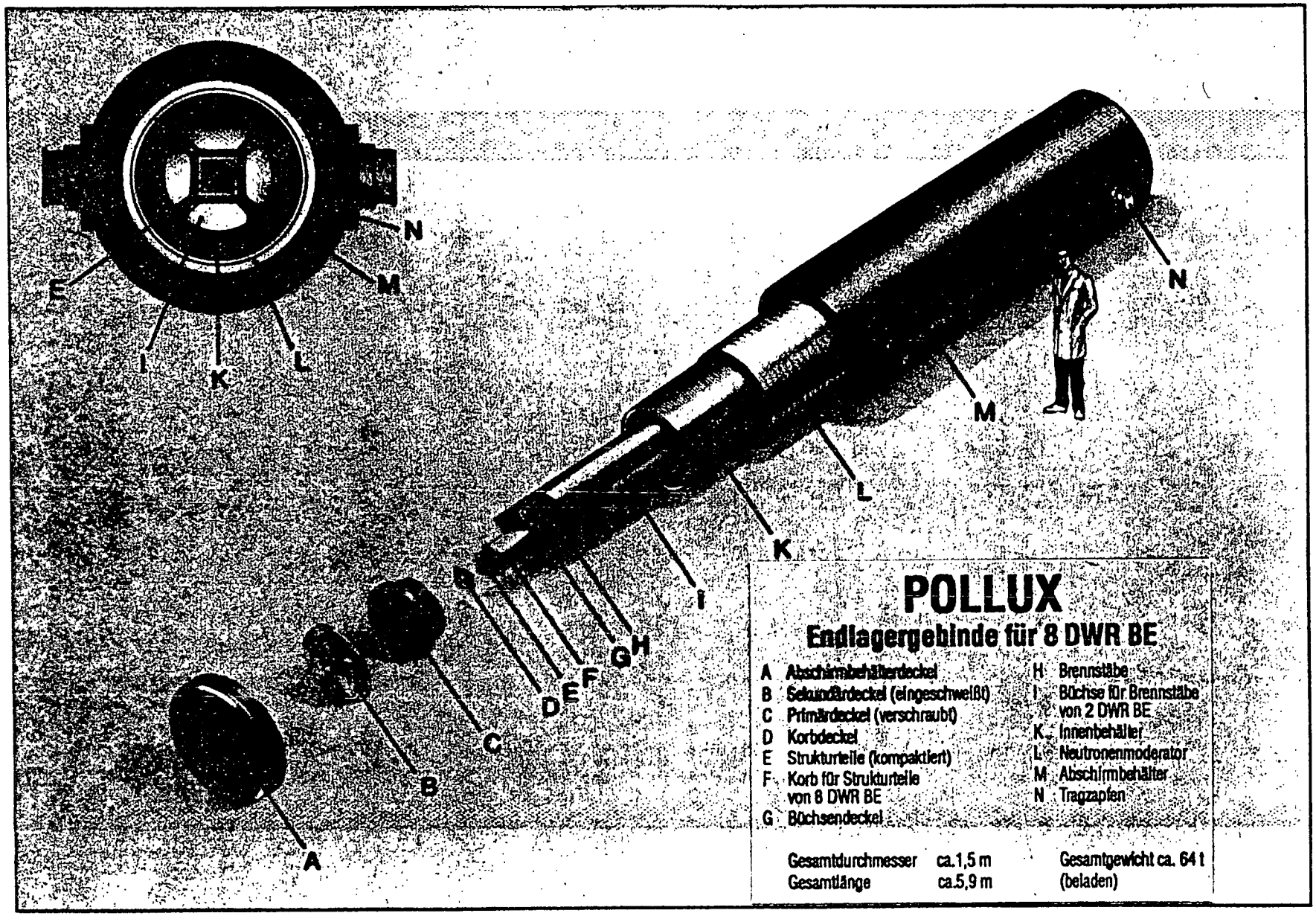

GNS	Endlagerbehälter POLLUX	02/1988

FRG Concept for a HAW Repository

- Repository in a Permian salt formation
- Disposal at a depth of 800 meter below ground
- Stacking of HAW canisters in 300 meter deep unlined boreholes
- Dose rate at the canister surface: $2{,}5 \times 10^3$ Gy/h
- Specific heat power of HAW: 17 watts/liter
- Maximum permitted salt temperature: 200 °C
- No retrievability

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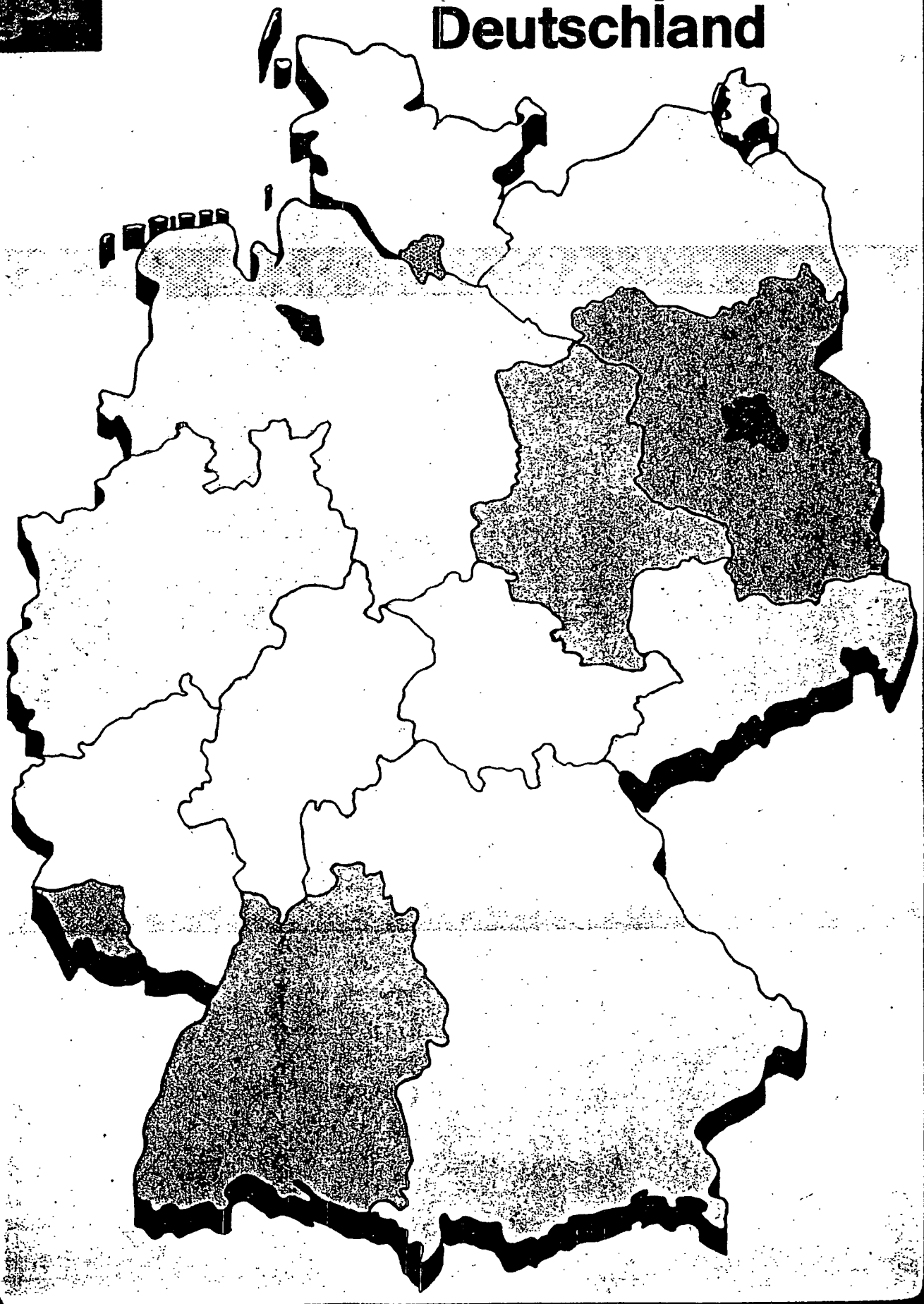
Bundesrepublik Deutschland

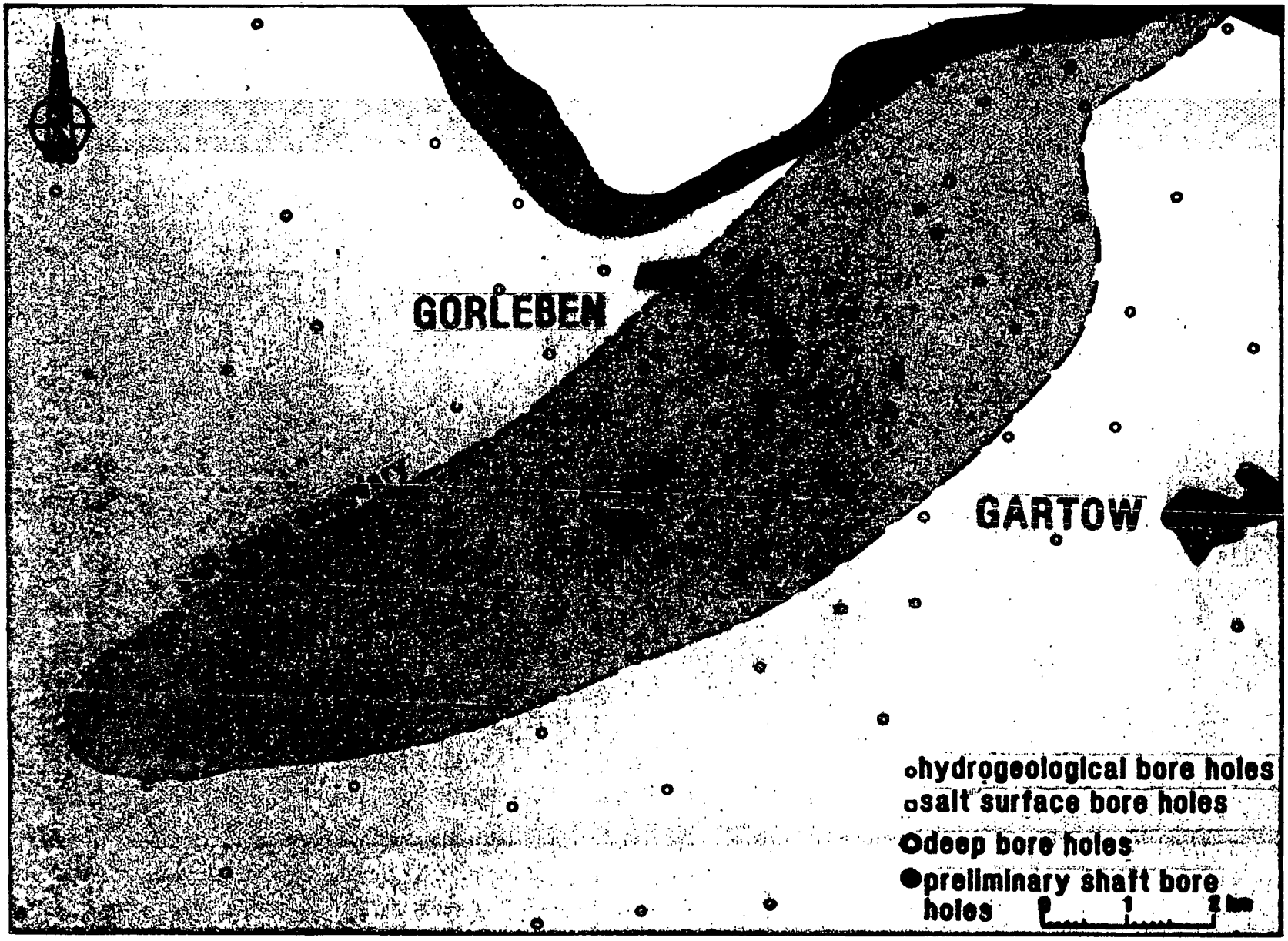


Gorleben

Morsleben

Asse

Konrad



The Gorleben Salt Dome Exploratory Investigation Drilling Program

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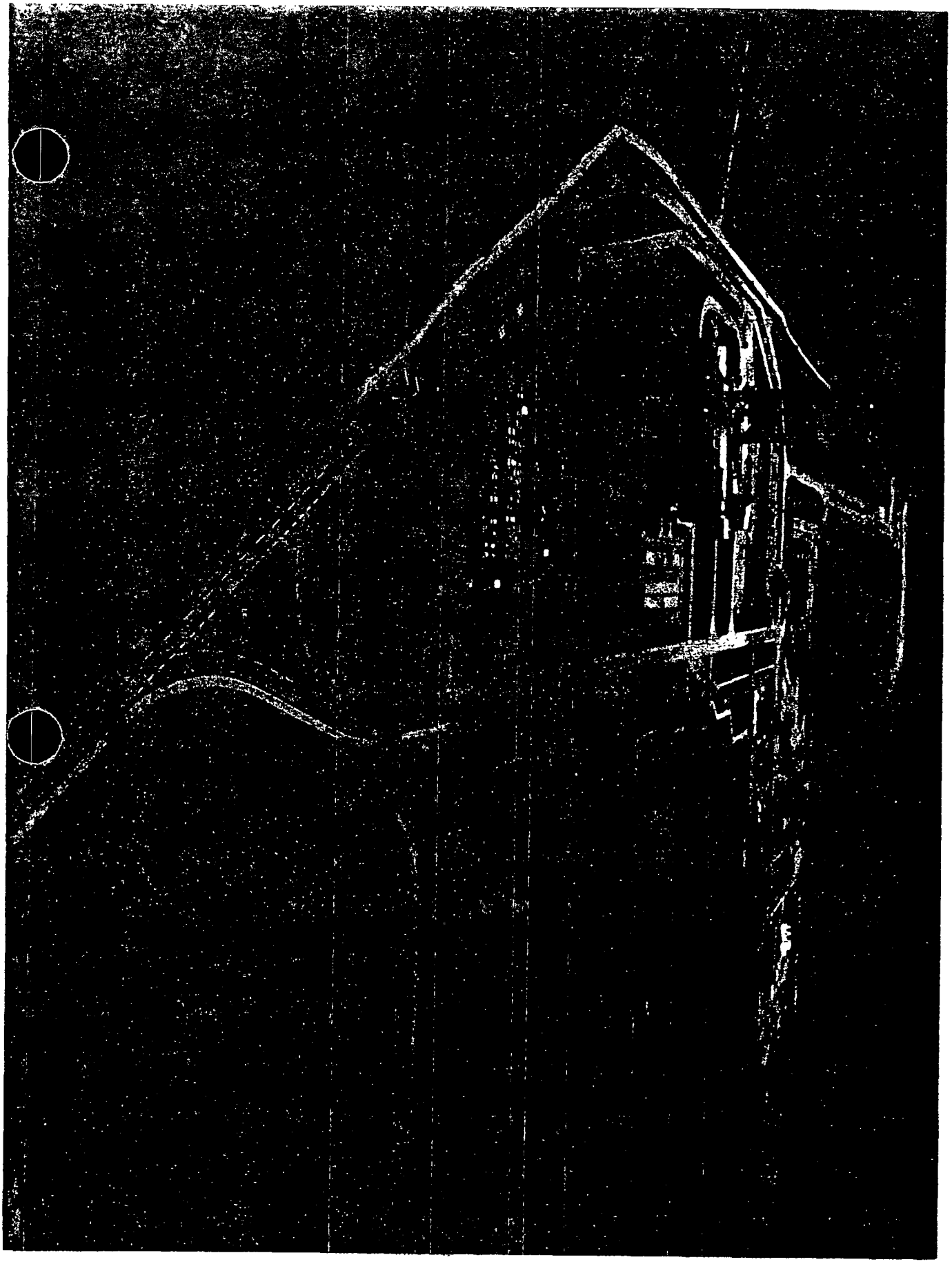

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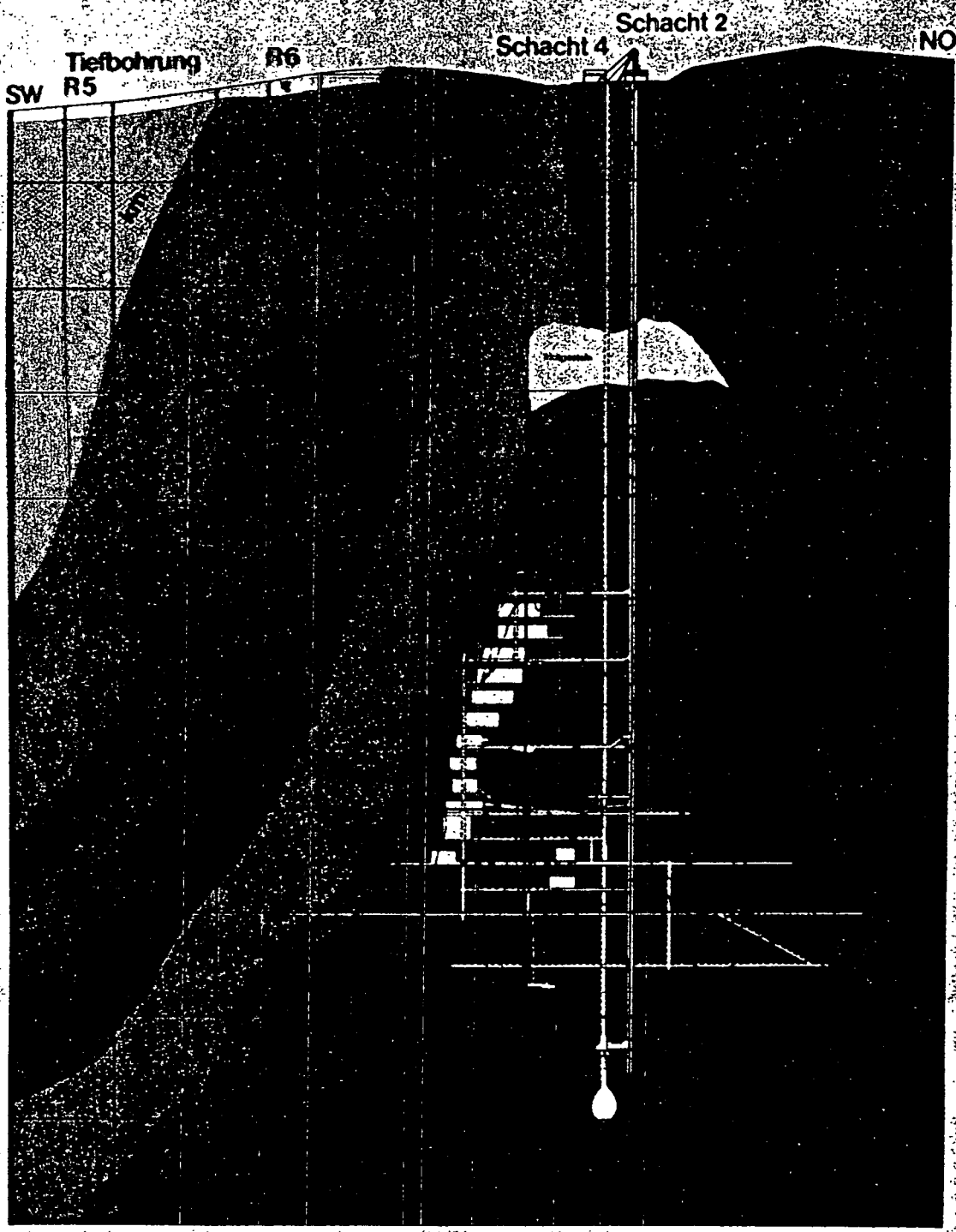
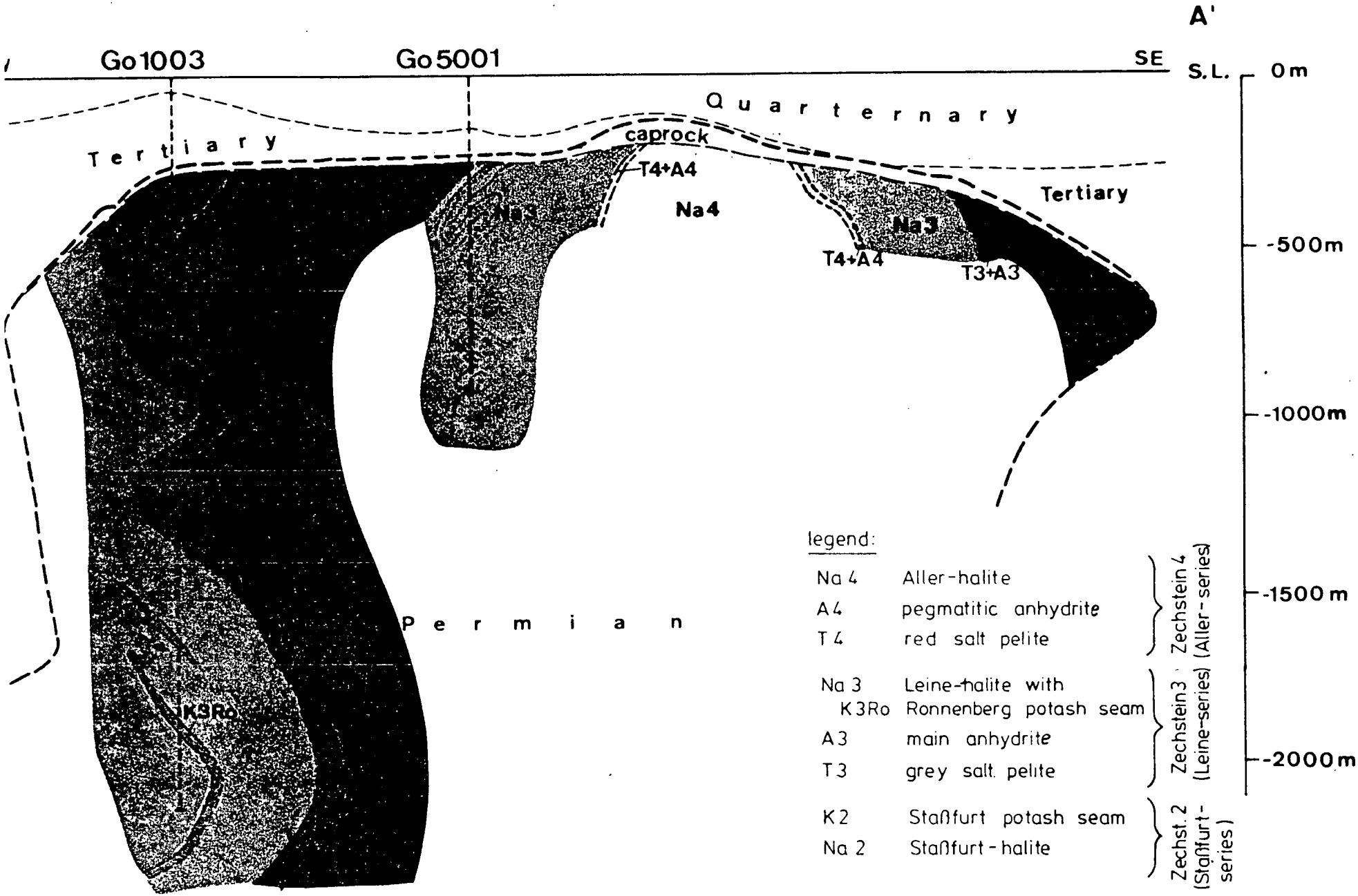
Schachtanlage Asse
Schnitt Südwest - Nordost




A'
Go1003
Go5001
SE
S.L.
0m
-500m
-1000m
-1500m
-2000m
Quarternary
Tertiary
caprock
T4+A4
Na4
Na3
T4+A4
T3+A3
Tertiary
Permian
K3Ro
legend:
Na 4 Aller-halite
A4 pegmatitic anhydrite
T 4 red salt pelite
Zechstein 4 (Aller-series)
Na 3 Leine-halite with
K3Ro Ronnenberg potash seam
A3 main anhydrite
T3 grey salt pelite
Zechstein 3 (Leine-series)
K2 Staßfurt potash seam
Na 2 Staßfurt-halite
Zechst. 2 (Staßfurt-series)

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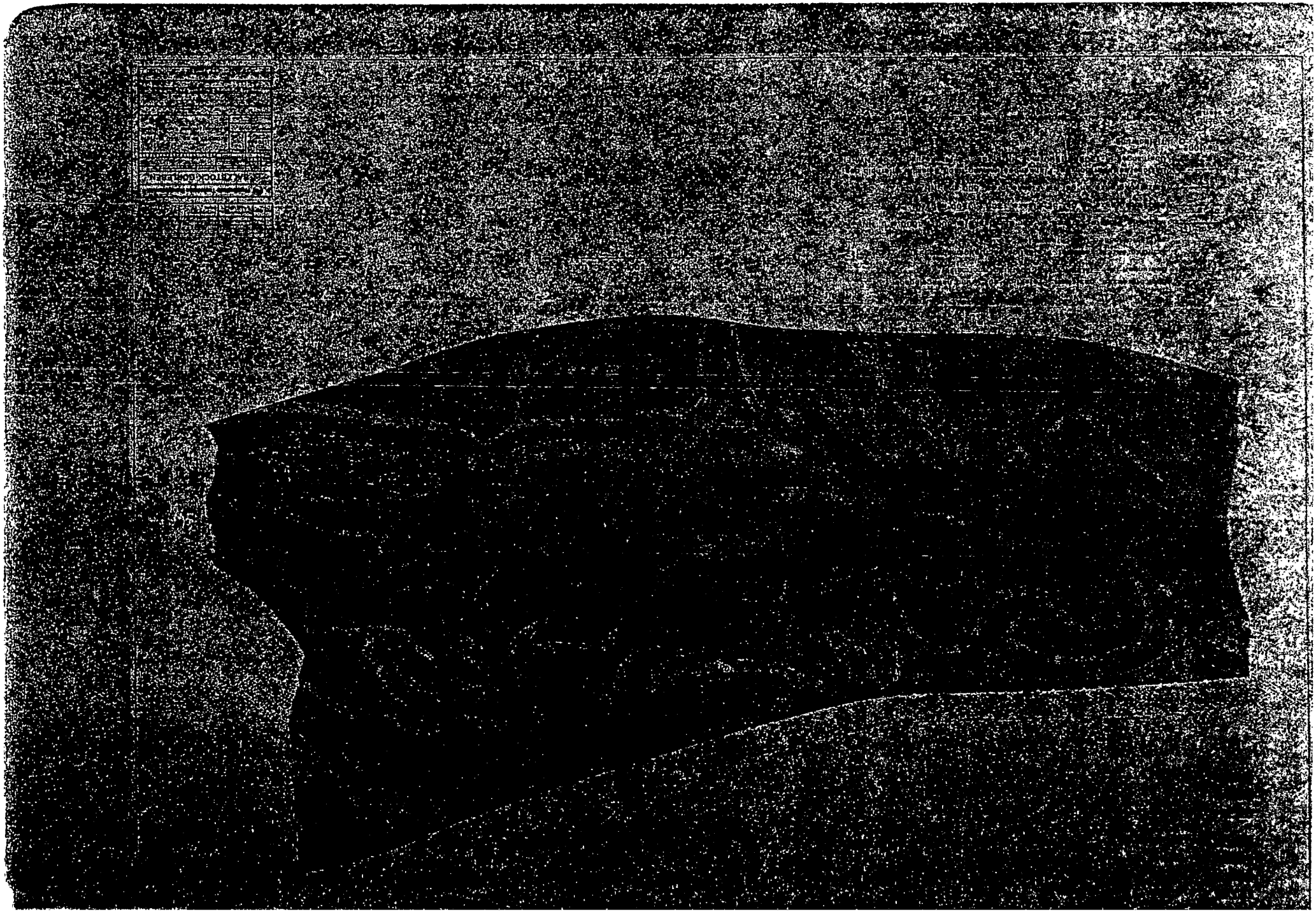
Mittlere Zusammensetzung des

	Oberen Staßfurt-Steinsalzes der Asse (ca. 250 m Profil)	Staßfurt- und Leine-Steinsalzes von Gorleben (BGR/PTB)
	in Gew. %	
Halit	94.3	96
Anhydrit	4.9	3
Polyhalit	1.5	
Kieserit, Carnallit (?)	< 1.0	< 0.5
Quarz, Magnesit, Tone	0.13	< 1

CARNALLITE

$KMgCl_3 \cdot 6H_2O$

Rock pressure [Bar]	Water release temperature [°C]	Thermal safety distance [M]
1	~ 85	~ 60
40	139	~ 40
100	145	



Drawing of Principle: System of the technical Barriers

Shaft backfilling

Shaft Sealing

at work

Dam

Backfilled

in Preparatory work

Dam

Borehole-Plug

Repository (at work)

In Preparatory work

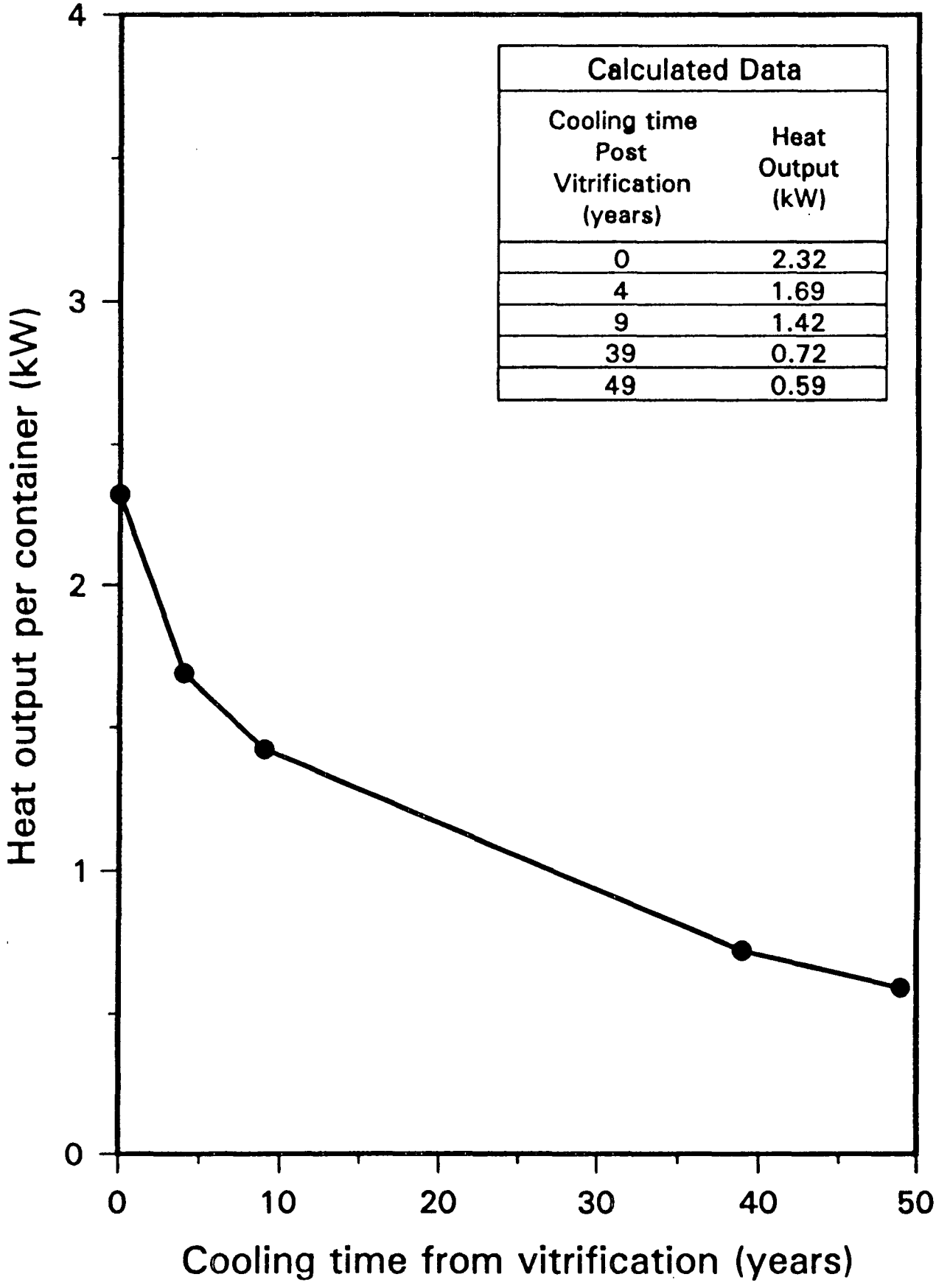
Backfill in the Drift

Bulkhead

Chamber backfilled

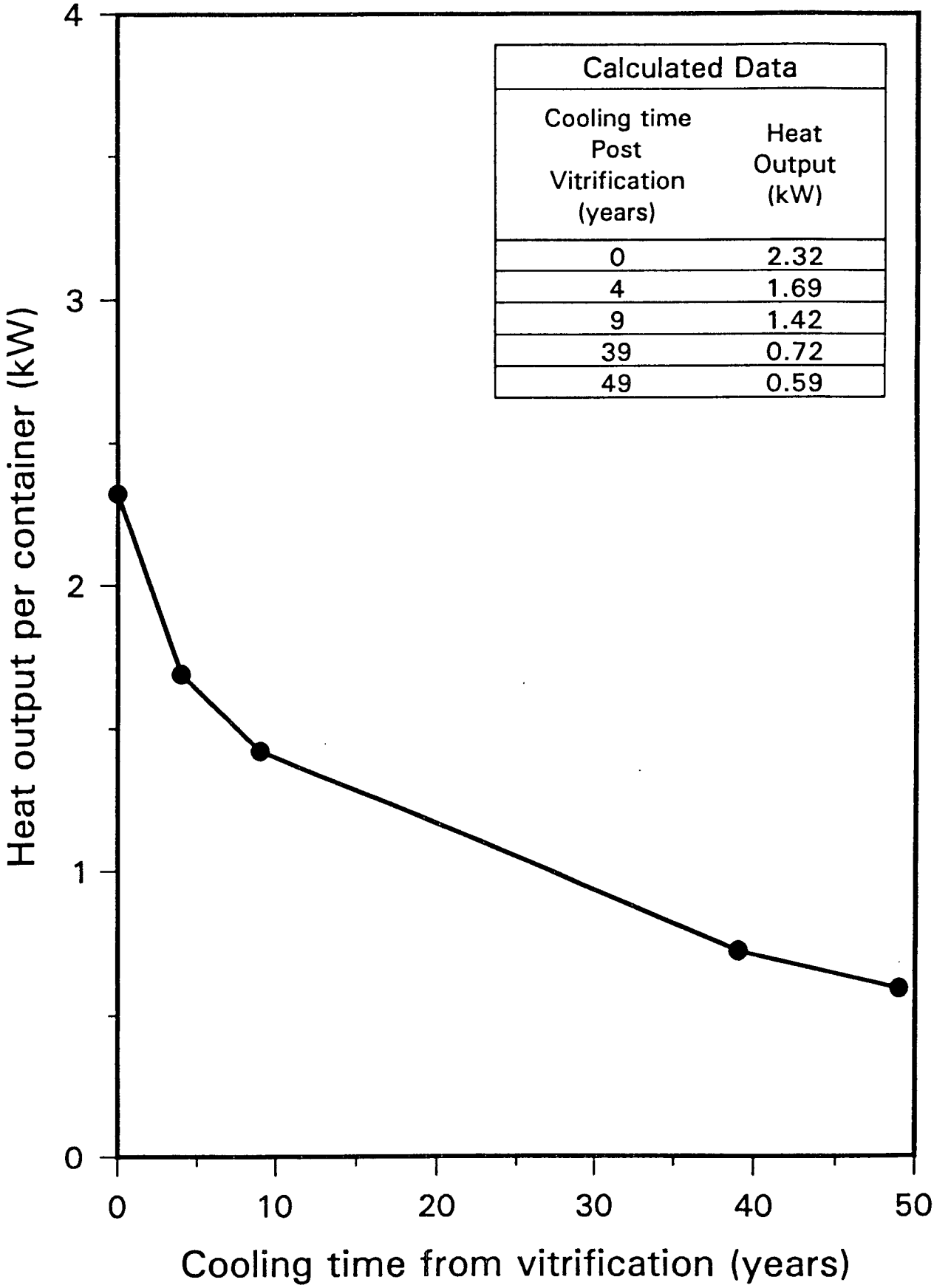
gsf

Thermal decay curve - PWR



Calculated Data	
Cooling time Post Vitrification (years)	Heat Output (kW)
0	2.32
4	1.69
9	1.42
39	0.72
49	0.59

Thermal decay curve - PWR



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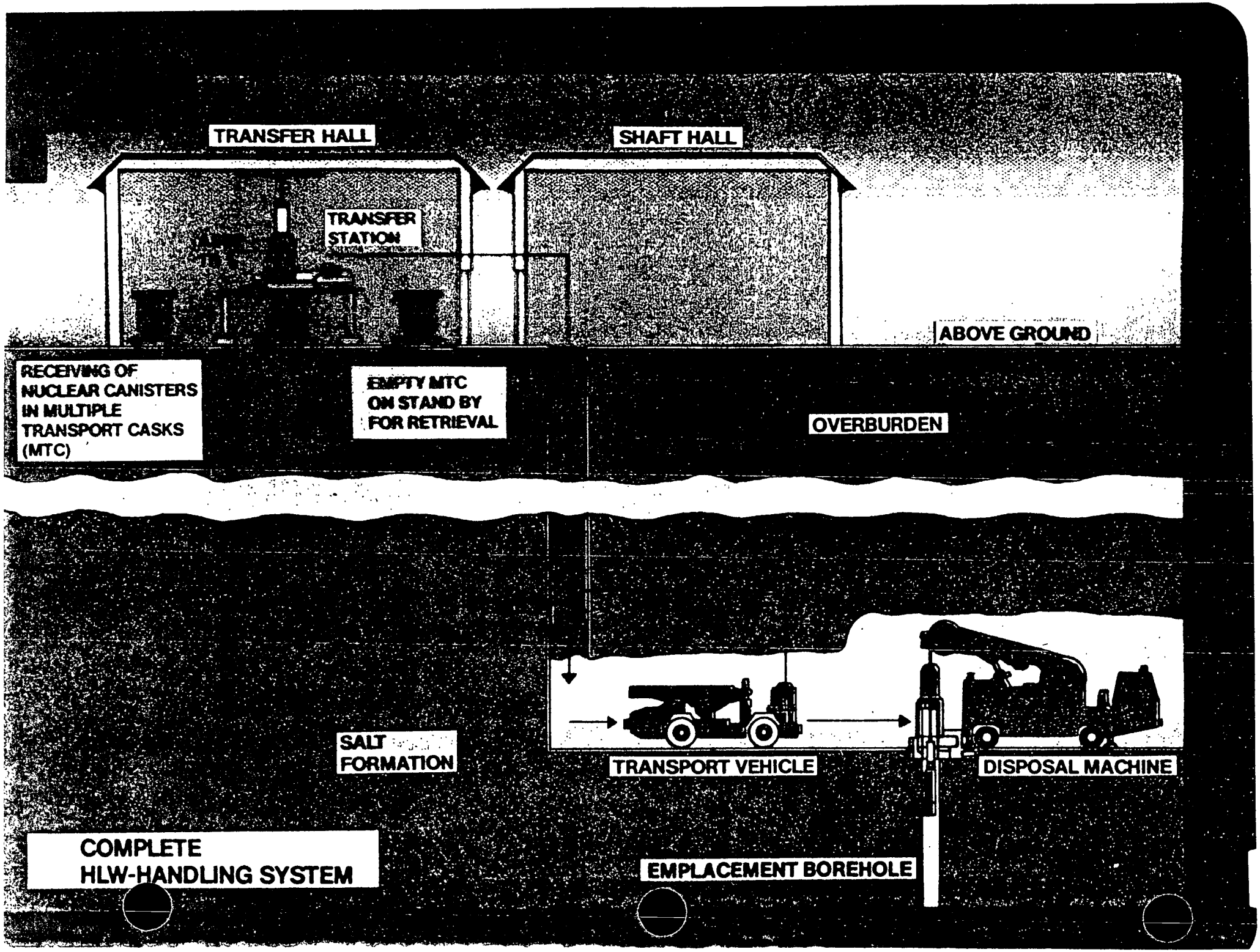

COMPLETE HLW-HANDLING SYSTEM

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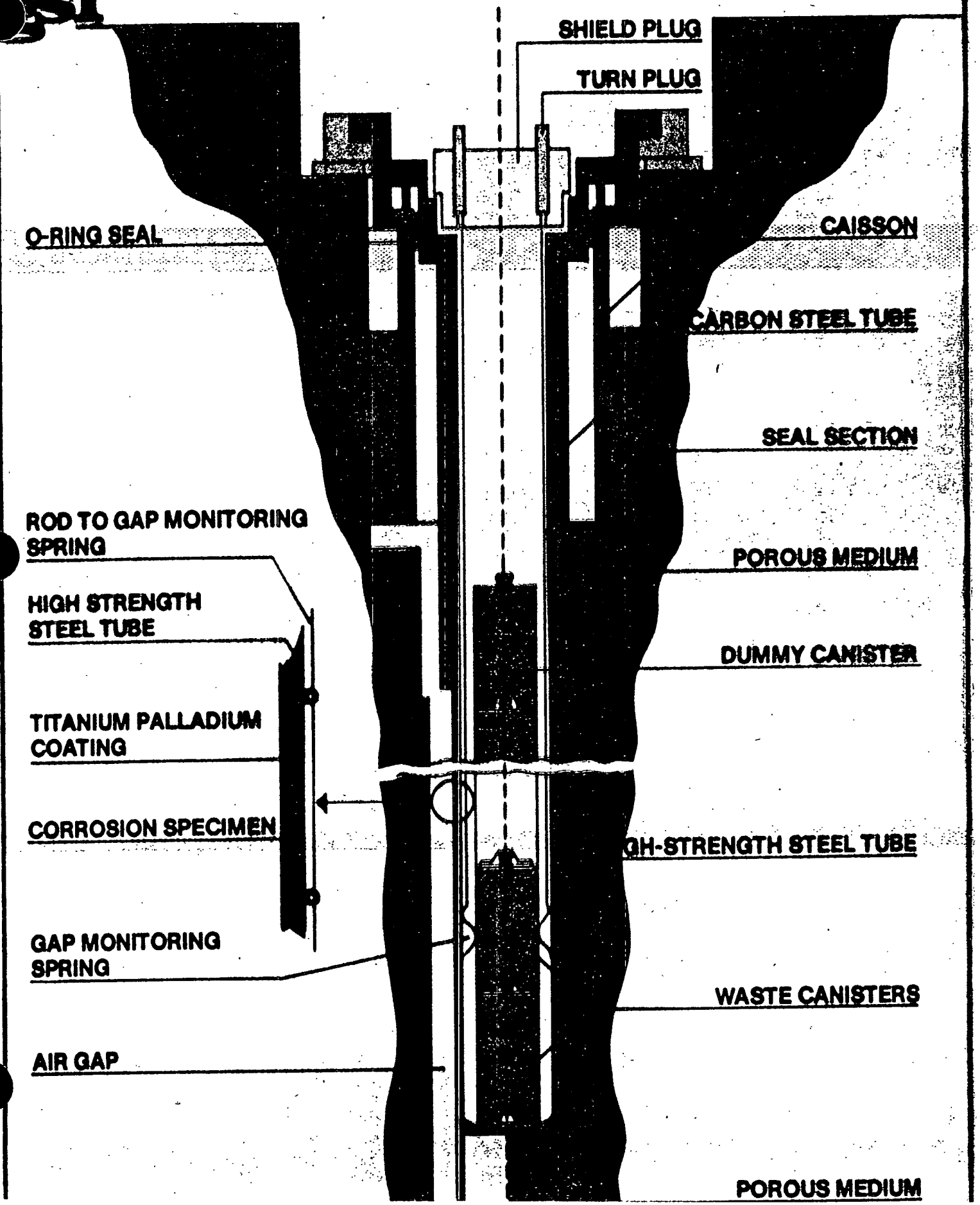
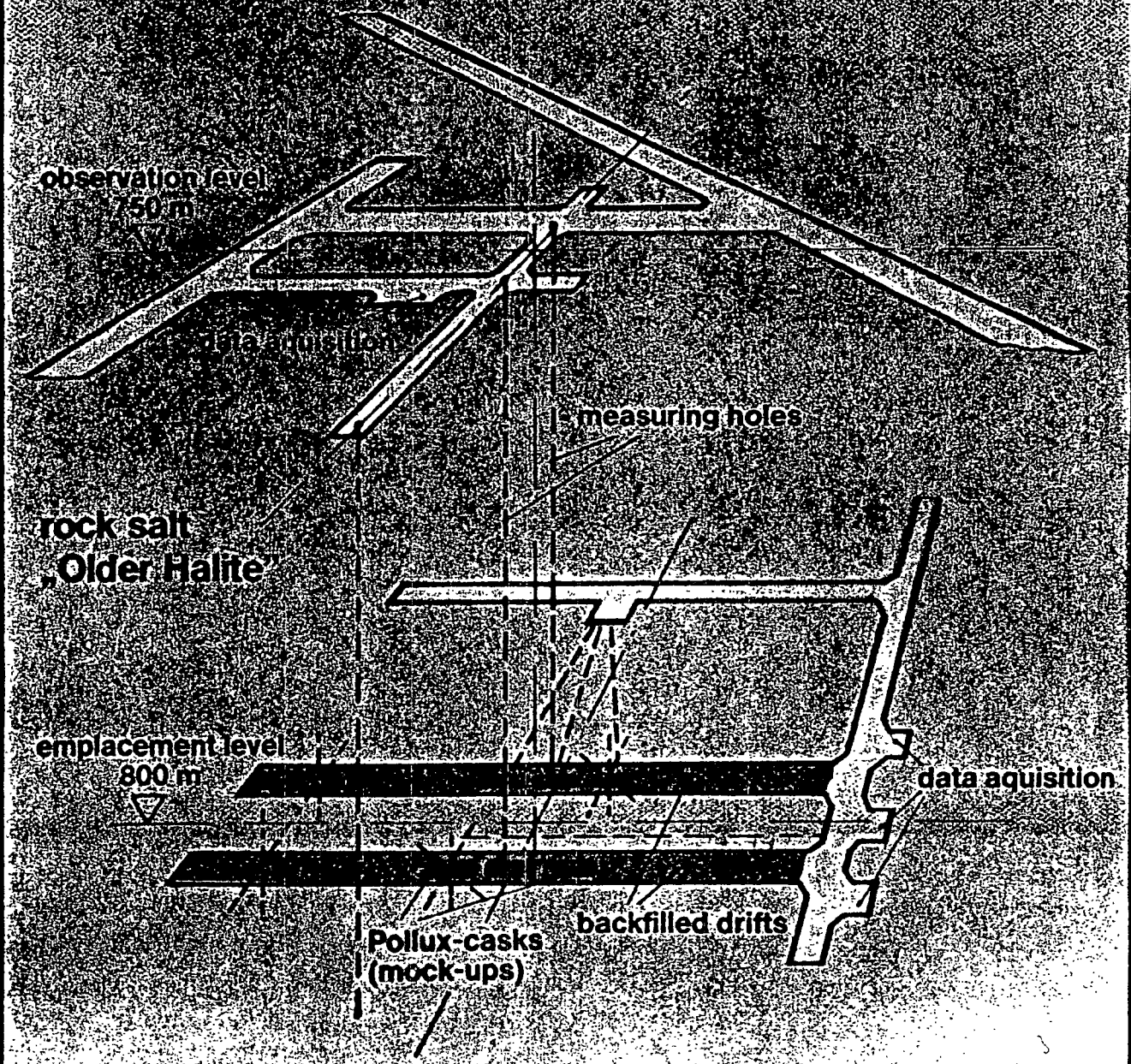
CROSS SECTION OF EMPLACEMENT BOREHOLE

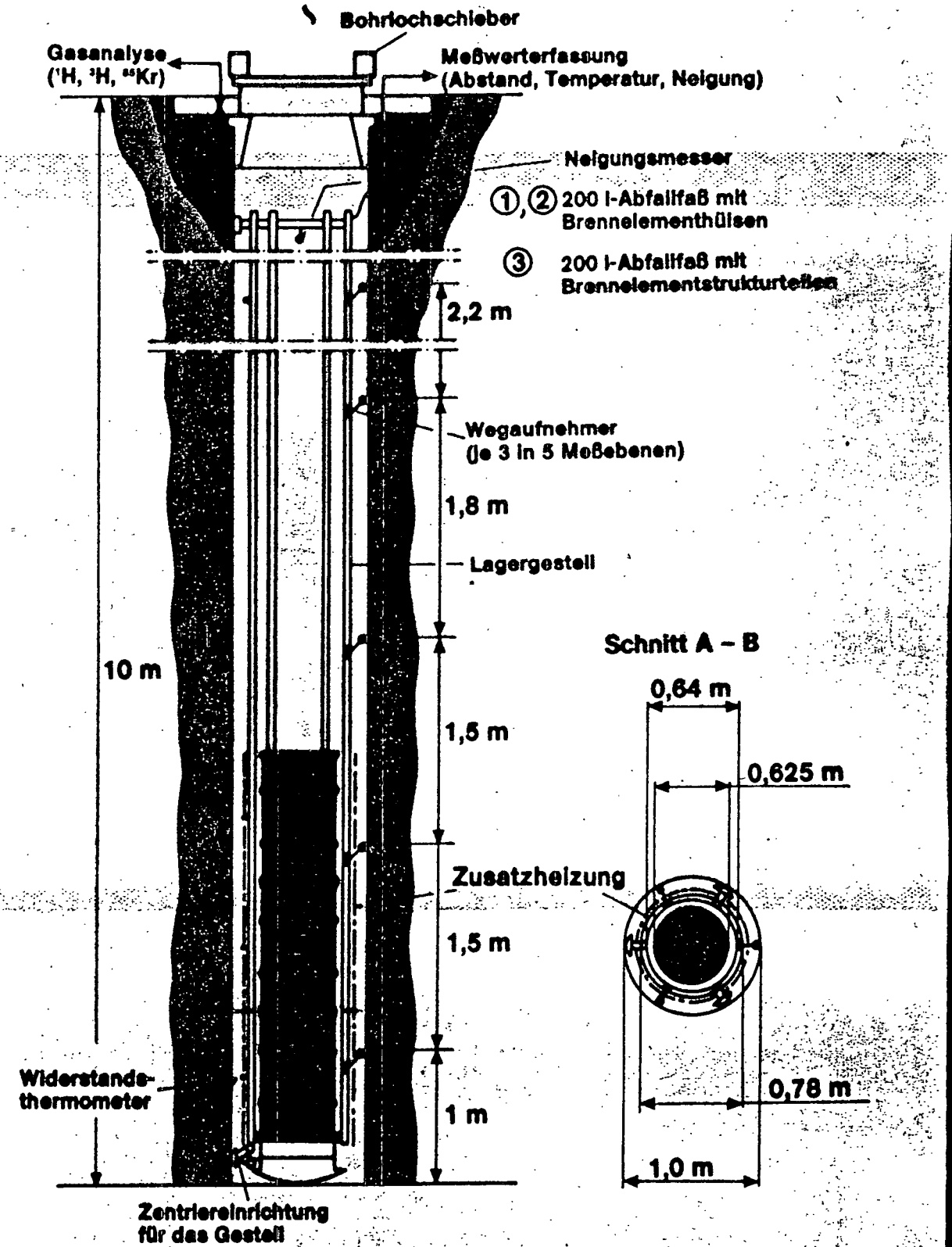


General view of the test site



März 1988

MAW- und HTR-BE-Versuchseinlagerung in Bohrlöchern



Ausrüstung von Bohrloch E 3 in der MAW-Versuchsstrecke EV (rückholbarer Einlagerversuch) mit 3 Abfallfässern mit Brennelementhülsen/ -strukturteilen)