# STABILIZATION OF THE CENTRAL PART OF THE MORSLEBEN REPOSITORY (BGZ)

W. Hund, G. Laumert, J. Preuss, G. Eilers, R. Mauke, R. Köster
Bundesamt für Strahlenschutz (BfS), Willy-Brandt-Straße 5, D-38226 Salzgitter, Germany

H. Fischer, J. Oppitz, C. Schrimpf , M. Kreienmeyer, N. Müller-Hoeppe
Deutsche Gesellschaft zum Bau und Betrieb von Endlagern für Abfallstoffe mbH,
Eschenstraße 55, D-31224 Peine, Germany

## ABSTRACT

The twin-mine "Bartensleben-Marie" situated in the Federal State of Saxony-Anhalt (Germany), was chosen, in 1970, to serve as a deep geological repository for the disposal of low and intermediate level radioactive waste. In 1978, the waste emplacement started in rock cavities at the mine's fourth level, some 500 m below the surface. Until the end of the operational phase, in 1998, about 36,800 $m^3$ in total of radioactive waste was disposed of. Now the repository is under licensing for closure.

Due to the recent potash and rock salt production, the central part of the Morsleben repository is mined out to a large extent, and due to the long period of time since excavation (50-75 years) as well as the short distance to the top of the salt plug, the central part appears to be mechanically highly stressed. In November 2001, a significant roof fall occurred in a cavity on the –297 m NN level, which was restricted area due to the danger of roof falls. Numerical calculations, geotechnical surveillance measures and in-situ observations show that the risk of a progressive failure in the central part of the Morsleben repository affecting repository safety cannot be excluded. Therefore, it was planned to stabilize the central part by backfilling a number of selected cavities by salt concrete prior to the closing procedures. The backfilling process started on October 8th, 2003. After having backfilled the selected cavities, the surrounding rock salt will act as a system of arches and pillars supporting the overburden and minimizing deformations of the main anhydrite which tends to brittle failure. By this stabilization measures the necessary safety level is achieved up to the final closure.

## INTRODUCTION

In 1970, in the German Democratic Republic, the Bartensleben Salt Mine was selected to serve as a repository for low- and intermediate-level radioactive waste with negligible heat generation. Located close to the village of Morsleben, about 100 km east of Hanover, the facility was named "Morsleben Repository for Radioactive Waste (Endlager für radioaktive Abfälle Morsleben – ERAM)". Following studies and the successful demonstration of the disposal technologies used, the operational license was granted in 1981. Subsequent to the German reunification on October 3rd, 1990, the Federal Government of Germany took over the responsibility and the facility got the status of a federal repository. The disposal of waste was terminated on September 28th, 1998. Now the repository is under licensing for closure.

A closure concept has been established which is based on a comprehensive backfilling of the excavations with a hydraulically transported salt concrete. The function of the backfill is to stabilize cavities as well as to reduce the mine's opening volume and to seal single cavities or groups of cavities containing radioactive waste [1,2].

However, in the highly excavated central part of the mine, stabilization measures are performed in advance to guarantee a regular plan-approval procedure for closure later on. Due to the age of the mine creep induced failure cannot be excluded, as shown by a roof fall in the central part which happened on November 30th, 2001. Based on geomechanical calculations, geotechnical surveillance measures, and in-situ observations safety is used up gradually.

## LOCAL GEOLOGY, MINING CONDITIONS AND RADIOACTIVE INVENTORY

The ERAM is located in the structure of the "Allertalzone" , named after the small river Aller, covering an area of about 50 $km^2$. Tectonically it is a fault structure, due to extension tectonics which separates the Lappwald block and the Weferlinger Triassic block. Into the fault zone Permian evaporate strata intruded and accumulated to a plug forming the now existing salt structure. The top of the salt leaching surface is at 140 m below mean sea level and the thickness of the salt body varies between 380 m and 500 m.

The salt body is characterized by an intensive folding of the layers and a high amount of anhydrite rocks, such as the main anhydrite ("Hauptanhydrit") of the Leine-formation (z3HA). The stiff anhydrite layers, broken into blocks during the flow of the plastic salt strata stabilize the internal salt structure and lead to low convergence of mine excavations. Another feature of the deposit is the occurrence of potash seams which mainly are carnallitite and kiseritic hartsalz. In general, the evaporite layers and the tectonic elements, such as folds, follow the border of the structure.

The salt leaching surface forms a more or less flat plane at a depth of approx. 140 m below mean sea level. The leaching surface displays a certain relief with depressions in some places with a proved maximum of approx. 175 m below mean sea level. The overlying cap rock has a very low hydraulic conductivity and isolates the salt structure from the aquifer system in the overlying upper Cretaceous rocks. The aquifer is overlain by unconsolidated or semi-consolidated glacial sediments. In addition, the surface cover is provided mostly by Quaternary sediments.

The ERAM is a twin-mine consisting of the concessions Marie and Bartensleben (Fig. 1). It is 5.6 km long and has a maximum width of 1.7 km. The two shafts provide access to a widespread system of drifts, cavities and blind shafts between 320 m and 630 m below the ground surface. Prior to waste disposal, rock salt and potash mining went on at the site for several decades. Thus most of the mining openings are a result of salt production activities. The cavities made by chamber working have dimensions up to 100 m in length, in a few cases up to 200 m, and 30 m in width and height. An important difference between the mining fields is that Bartensleben produced much more rock salt (approx. 5 million $m^3$) in relation to potash salt (approx. 0.7 million $m^3$), whereas in the Marie mine the exploited volume of potash salt (1.4 million $m^3$) is much higher than the volume of the produced rock salt (0.7 million $m^3$). Including shafts, drifts and infrastructure rooms the overall volume of the cavities amounts to more than 8 million $m^3$ (Fig.1), of which more than 2 million $m^3$ have been backfilled mainly using crushed salt.

During the operational period of the repository about 36,800 $m^3$ of radioactive waste had been disposed of. The disposal rooms are located in the periphery of the Bartensleben mine, above all in the western, southern and eastern fields, see Fig. 1. Very low amounts of waste are emplaced in the central part and the northern field. The activity of the waste and its volume is given in Tab. I.

Table I Volume and Activities of Disposed Waste

| **Disposal area** | **Waste volume [$m^3$]** | **Activities [Bq]** |
|---|---|---|
| Western field | 18,637 | $2.3 \cdot 10^{13}$ |
| Southern field | 10,119 | $8.2 \cdot 10^{13}$ |
| Eastern field | 6,139 | $1.1 \cdot 10^{13}$ |
| Northern field/central part | 1,858 | $4.1 \cdot 10^{12}$ |

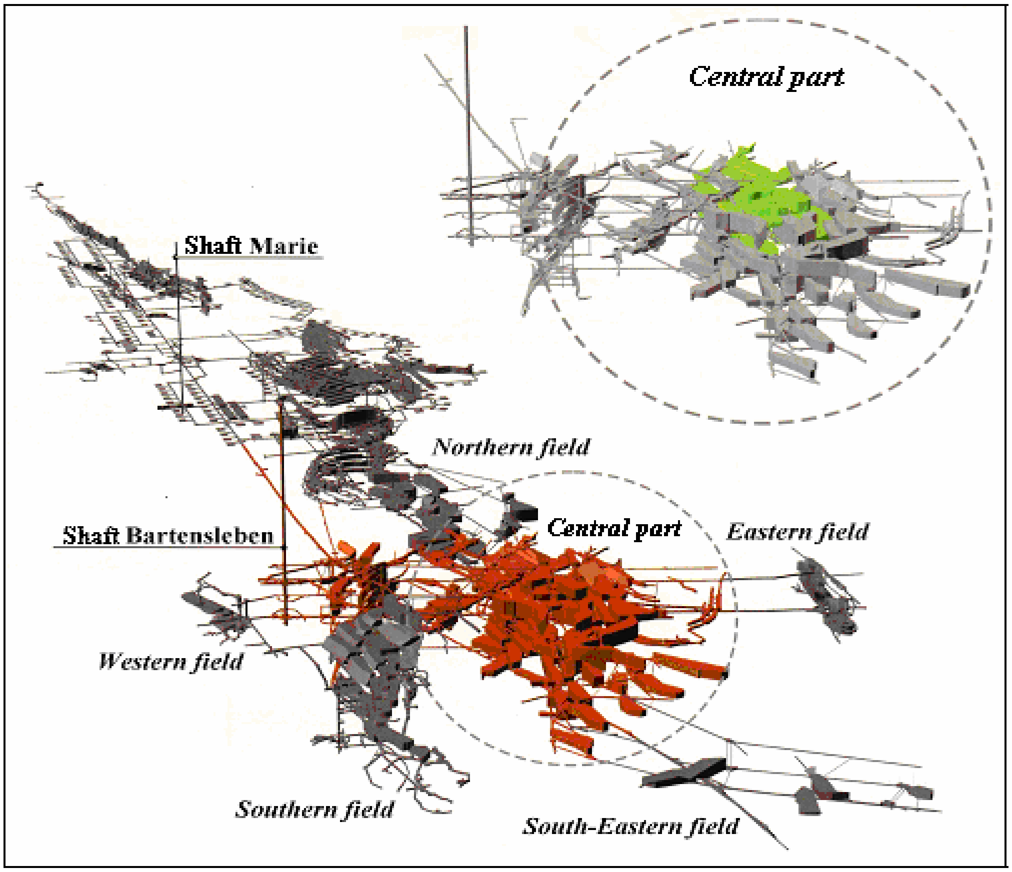


Fig. 1 Mine openings and cavities of the central part to be backfilled in advance (green)

## STABILIZATION MEASURES

To stabilize the central part of the mine in advance a number of selected cavities are backfilled by salt concrete (Fig. 1). The backfilling of these cavities and the surrounding rock salt act together as a system of arches and pillars (Fig. 2) supporting the overburden and minimizing deformations of the main anhydrite, which tends to brittle failure and may act as future pathway for radionuclide transport.

The technical concept to avoid failure of highly stressed elements as pillars and roofs as well as a loss of integrity of the salt barrier consists in backfilling 20 excavations (total volume: approx. 670.000 $m^3$). By using salt concrete (M2) as backfilling material the void volume will be reduced in order to maintain the stability and integrity of the remaining system. The backfilling material consists of cement, coal fly ash and crushed rock salt, mixed with water or brine.

The salt concrete is produced in a production unit adjacent to the repository site and transported to the stationary pumping station at the Bartensleben shaft by pipeline. During the first six months ready mixed salt concrete is delivered by trucks and a mobile pumping unit is used. The underground pipeline system for salt concrete transportation covers approx. 425 m vertical and up to approx. 1.200 m horizontal distances.

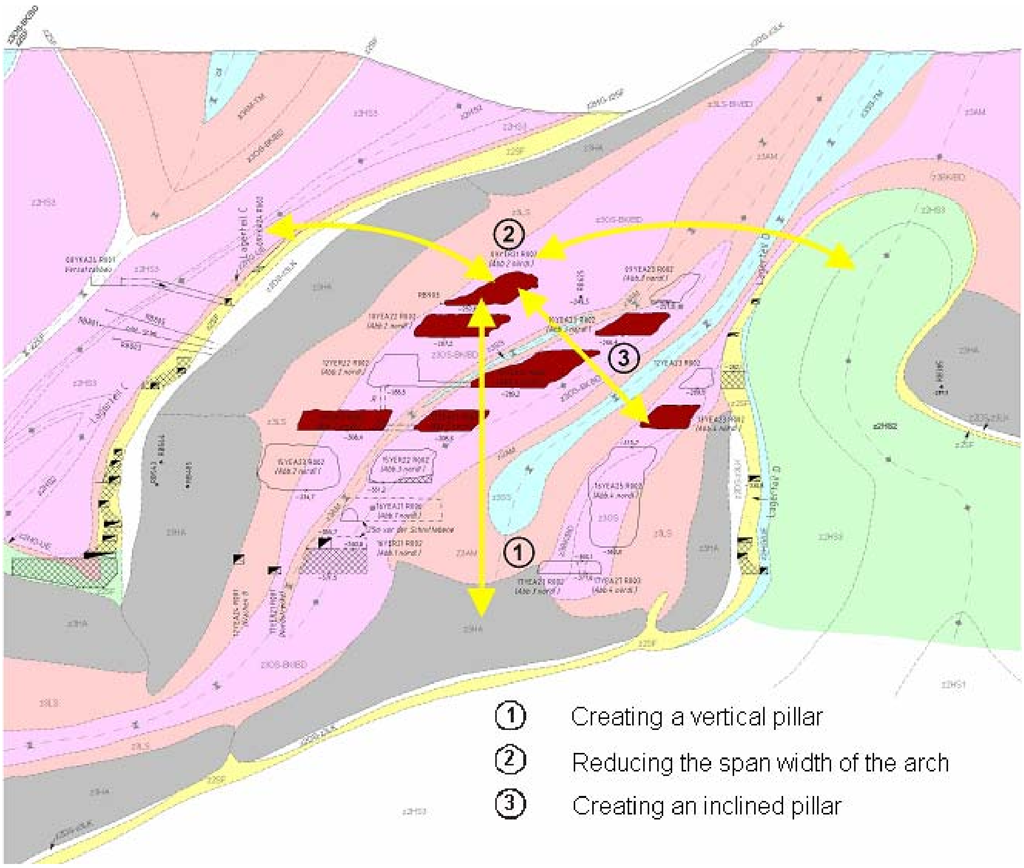


Fig. 2 System of arches and pillars due to stabilization measures.

## SAFETY PROOFS AND SAFETY MEASURES

For licensing the stabilization measures of the central part in advance several safety proofs were performed and safety measures described. The same safety criteria as for the closure concept are examined. Applicable criteria resulting from the German regulations, e.g. the Federal Mining Act, the Water Protection Act and the Radiation Protection Ordinance are given in [1,2] with

(1) Subsidence < 1 m or inclination rate of the ground surface < $^{1}/_{300}$ in 100 years.

(2) The excavation damaged zones (EDZs) around the cavities are estimated on the basis of the dilatancy and the fluid criterion. Excavations in an unfavorable geologic situation are specifically considered in the long-term safety analysis. With respect to an acceleration of leaching processes the temperature increase at the salt table is limited to 1 K. The temperature rise of potential pathways of fluids is limited to 2 K.

(3) The criterion for the avoidance of leaching processes which may reduce the seal efficiency, bases on the NaCl saturation of the brines.

(4) On the basis of the long-term safety analysis an average cross section permeability $k^i < 10^{-18}$ m² of the seals is necessary (German licensing criterion 0.3 mSv/a).

(5) Compliance with classical mining occupational health and safety (see e.g. Climate Mining Ordinance), safety in handling the backfill material (see Health Protection Mining Ordinance). Avoidance of pumping water contaminated with radionuclides.

(6) Permissible substance concentrations in eluats (see Water Protection Act).

Since sealing is not part of the stabilization measures in advance, criterion (3) and (4) are not considered in this case.

Regarding criterion (1), (2) and (5), numerical calculations were carried out and compared with in-situ observations. Starting from the primary state of stress the numerical calculations cover the excavation phase and the convergence of the cavities up to the beginning of the backfill process. Then, the backfill process is simulated and further calculations cover a period of 1.000 years after backfilling.

It was shown that the influence of hydration heat on potential pathways is negligible. The calculated temperatures comply the temperature criteria given in safety criterion (2). Evaluation of the dilatancy criterion before and after backfilling (Fig. 3) demonstrates the improvement of the geomechanical situation.

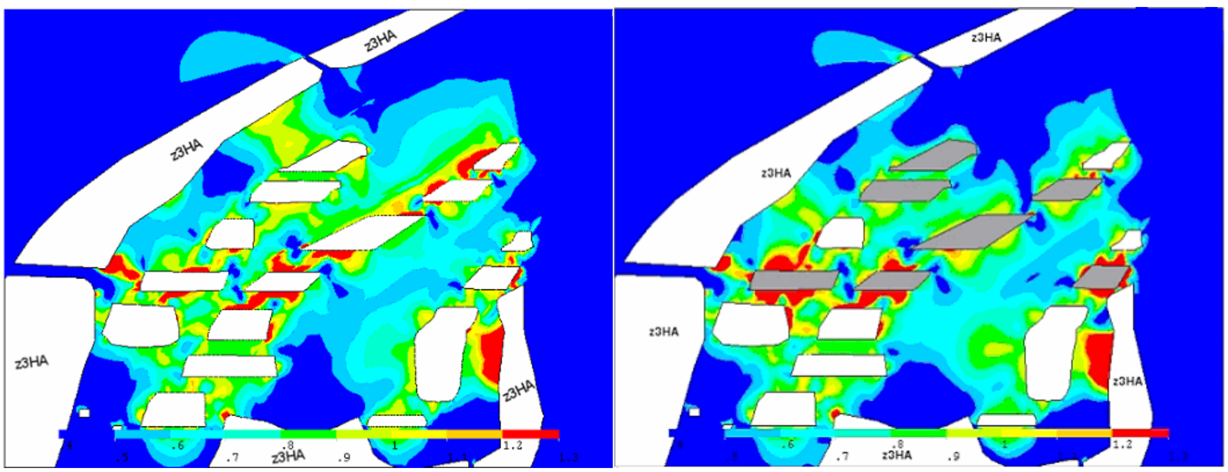


Fig. 3 Stress regimes (dilatancy boundary 1.0) before (A) and after (B) backfilling of the excavations (central part). The yellow, orange, and red areas mark a violation of the dilatancy criterion. Backfilled openings are marked dark gray (salt concrete).

In some cases the numerical calculations show an insufficient safety level for a short period of time during or shortly after the backfilling procedure. Thus the safety assessment has to be supported by the observation method. A geotechnical surveillance program was developed in order to guarantee occupational safety, and a provisional concept is available describing suitable organizational measures. Additionally, the geotechnical measurements in ERAM serve to prove effectiveness of the measures and the monitoring of the state of the rock before, during and after the realization of the stabilization measures in geomechanically exposed supporting zones. By monitoring before backfilling, data is collected which can be used for improving the numerical model.

Radiological occupational health and safety (criteria (5)) is ensured by working regulations following the Radiation Protection Ordinance.

Concerning criterion (6), the ingredients of the salt concrete are regarded. The eluate values are controlled by a laboratory test program.

Finally, a proof of compatibility was established to assure that the previous stabilization measures of the central part are compatible with the planned closure concept [1,2].

## IN-SITU TEST

After having performed a large number of small scale and intermediate scale laboratory tests [3,4] and before starting the backfilling process, an in-situ drop test was performed in a blind shaft, to assure that the transportation process does not affect the quality of the backfill. Investigating core samples from the backfill showed adequate properties of the salt concrete as well as a good adhesion to the rock salt contour. As it was planned to stow the fresh concrete via boreholes into the openings, theoretical considerations and the in-situ free fall test proved that a separation of the concrete components during the dropping into the excavations can be excluded. Drilling cores through the concrete body of the free fall test reveal a rock quality designation index (RQD index) of 100 %, indicating that a good quality of concrete bodies will be achieved. The mineral saturation of the hydrous solution of the concrete impedes reactions with rock salts and anhydrite rocks.

## BACKFILLING PROCESS

In March 2003, the necessary mining activities for infrastructure preparation in the Morsleben repository were started. After a test phase the stabilization process of the central part started on October $8^{th}$, 2003, by backfilling a first cavity which is not affecting occupational health and safety. Fig. 4 shows the production unit.

Following the quality assurance program, different tests of the backfill material are performed. As a field quality control test the slump test according to the guideline to self compacting concrete is carried out. It gives a reasonable indication how easily a mix can be placed and is simple to perform. The pressure gradient during the pipeline transport of the fresh concrete can be derived from the measurements.

Although a sufficient safety level for occupational health and safety is given during backfilling of the first cavity, the process is monitored by measuring devices for temperatures and stresses to establish a data base to assess more sensitive structure at cavities which will be backfilled later on.

Using these measured results of the backfilling process the numerical model for simulation of the backfilling process is improved by calibration and becomes further validated by in situ data. Taking into account the geotechnical surveillance program additionally, as a result two validated numerical models are available, a first model describing the geomechanical situation of relevant structures (ceilings of cavities) before backfilling (calibrated due to measurements before backfilling) and a second model describing the backfilling process (calibrated due to measurements during backfilling). The two models will be coupled to predict the future deformation behavior of the ceilings with special regard to the positions of measuring devices.

Assuming a daily backfilling rate of 300 to 580 $m^3$ of salt concrete, the stabilization of the central part of the Morsleben repository will be accomplished by 2008.


Fig. 4 Production unit adjacent to repository site (shaft Bartensleben in the background).

**CONCLUSION AND OUTLOOK**

Evidently, the stabilization measures of the central part were planned and tested in detail. Relevant proof of safety as well as safety measures were performed and described in advance. A geotechnical surveillance program was developed and installed.

In October 2003, the realization phase started by backfilling the first cavity with salt concrete. In proceeding with the backfilling process in the next phase the numerical models will be improved by further calibration and validation due to data, i.e. measured displacements, stresses, and temperatures arising from the geotechnical surveillance program and monitoring the backfilling process.

In the next step cavities will be backfilled which are more sensitive with respect to occupational health and safety.

**REFERENCES**

1 Preuss, J. et al: Post Closure Safety of the Morsleben Repository, WM´02 Conference, 2002

2 Eilers, G. et al.: Sealing of the Morsleben Repository, Germany, WM´03 Conference, 2003

3 Skrzyppek, J. et al.: On backfill Material for an Underground Repository, DISTEC 2000, Sept. 4-6, 2000

4 Köster, R. et al.: Development of backfill materials in an underground salt repository,

5 International Workshop on Design and Construction of Final Repositories - Backfilling in Radioactive Waste Disposal, March 11–13, 2002, Brussels, Belgium

**FOOTNOTES**

[i] The permeability requirement was varied during the planning process