THERMAL SIMULATION OF DRIFT EMPLACEMENT GEOTECHNICAL AND GEOPHYSICAL INVESTIGATIONS IN AND AROUND BACKFILLED GALLERIES

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ABSTRACT

The concept for the direct disposal of spent fuel in rock salt foresees the emplacement of large waste canisters of 6 m lenth and 1.5 m diameter on the floor of a disposal gallery. Subsequent to emplacement the drift is backfilled with salt grit.

In a demonstration test, six cylindrical containments are to be emplaced withindistances of 3 m from each other in two parallel galleries of 14 m^2,separated by a pillar of 10 m thickness. They will be heated up by a power output of approximately 1 kW/m to 200°C surface temperature by electrical heaters. The thermal and mechanical response of the salt rock and the backfilling to the artificial heating is to be investigated as follows:

- measurement of the temperature field at the container surface, in the backfill and in the rock salt
- deformation measurements of the salt rock around the heated drifts
- measurements of tunnel convergence in heated and unheated sections
- compaction measurements of the backfilling in heated and unheated areas
- measurement of rockstresses in areas very close to the galleries
- pressure measurements in the backfilling, between backfilling and rock, between backfilling and containers

The rock burst monitoring system of the Asse salt mine will be expanded to this special field of the mine to detect seismic events due to thermomechanical effects. Another seismoacoustic system will be installed to observe the compaction of the backfilling. This system must be calibrated for the relation between the density and velocities of seismic waves. It is planned tomonitor the density by gamma-gamma log measurements. The changes in overall density during the entire experiment will be observed by gravimeter measurements of high precision.

Excavation, instrumentation and backfilling activities will continue until 1989. The heating phase will start at the beginning of 1990.

Investigations regarding the behavior of the backfilling material under heat and pressure load are to be carried out in the laboratory at the same time. The target of this program is the increase of the bearing capacity and the decrease of permeability of the backfill.

INTRODUCTION

The test site is located in the Older Halite at the 800 m-level in the Asse salt mine. It represents a cut-out of the drift system of a planned repository like that at Gorleben in the Fed. Rep. of Germany. At the 750 m-level and north of the test drifts at the 800 m-level, observation drifts enable the monitoring of the test site before, during and after the excavation of the emplacement drifts (cf. general view in Fig. 1).

The observation drifts at the 750 m-level were already driven at the end of 1987 by continuous mining. The access drifts at the 800 m-level are to be driven in the first half of 1988, and the instrument boreholes at the 750 m-level are to be drilled and instrumented. The emplacement drifts will be excavated at the end of 1988. In 1989 measuring devices and electrical mock-ups will be drilled from these at the 800 m-level.

The installation of the mock-ups and instruments in the drifts themselves are to be accompanied by successive stowing with a slinging truck. From the beginning of 1990 the sections of 24 m length in the center of the emplacement drifts will be heated with a power output of approximately 1 kW/m for about six years.

Planning and performance of the test program will be effected by four participants. Namely:

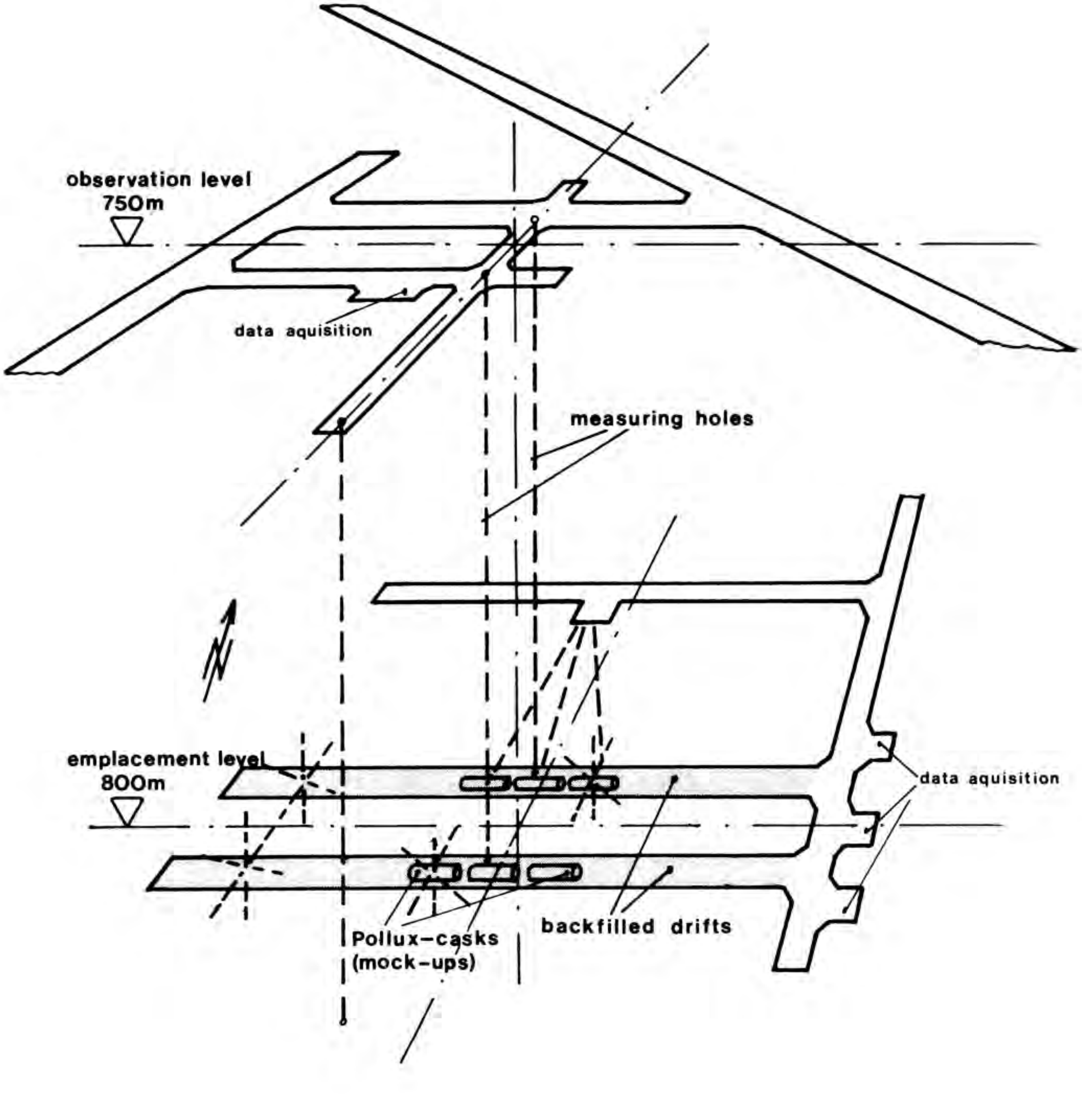


Fig. 1. General View of the Test Site.

- Bundesanstalt fur Geowissenschaften und Rohstoffe - BGR
- Deutsche Gesellschaft fur Bau und Betrieb von Endlagern fur Abfallstoffe - DBE
- Gesellschaft fur Strahlen - und Umweltforschung - GSF
- Kernforschungszentrum Karlsruhe - KfK

BGR carries out the large-scale thermomechanical calculations, measurement of the primary state of rock stresses and the secondary state in the farther surroundings of the emplacement drifts as well as the estimation of in situ-permeabilities in the rock salt and the backfilling. DBE is responsible for construction and emplacement of the mock-ups and selection of the technique for stowing and backfilling of the emplacement drifts. GSF carried out all mining activities. Within its R&D program GSF investigates the mechanical and physical reaction of the rock and backfilling to power input with geotechnical and geophysical methods. KfK handles the project management and thermomechanical modelling in the vicinity of the electrically heated mock-ups.

The geotechnical and geophysical investigations of GSF are described in this paper.

Geotechnical Investigations

To measure the thermal and mechanical response of the rock and stowing to power input, approximately 160 boreholes (with a total length of nearly 2,000 m), bottom, top and walls of the two emplacement drifts (70 m long each), the backfilling and the surface of the mock-ups are to be equipped with approximately 1,500 sensors, such as thermometers, rock-stress dynamometers, extensometers, inclinometers, pack-pressure dynamometers and settlement meters. The arrangement of the sensors is shown in the diagramatic view in Fig. 2. The measuring systems will be subjected to exceptional stress. During mounting of the mock-ups, which weight 65 tons, the systems at the tunnel surface are endangered by the heavy-duty traffic. During stowage the instruments will have to be sheltered from the slung salt grit. In the vicinity of the electrically heated mock-ups the sensors have to endure temperatures upto 200°C for a long time period. Finally, the test will last over several years and the convergence process, accelerated by heat, tries to close any cavity. Sooner or later the full rock pressure will come to bear upon the measuring systems in the boreholes and in the backfilled drifts. Basis for selection and arrangement of the sensors were the thermomechanical calculations carried out by KfK.

Deformation Measurements

The main reason for deformation in the test field is the convergence of the emplacement drifts. This movement is accelerated by heat and retarded by the load bearing capacity of the compacting backfilling. For registration purposes multifold rock extensometers are to be installed in boreholes in a star-like arrangement around the drifts and cross-cuts before, just at, between and behind the heaters. Reference marks are anchors at depths of 20 m or more in the rock. The appertaining deformation of the drifts is to be measured by convergence indicators in the same cross-cuts. The course of compaction of the backfill is also sampled at these locations by altimeters installed at different heights.

Stress Measurements

Knowledge of the entire stress field in the surroundings of the emplacement drifts is necessary to interpret the events around the heaters and in the backfilling. It is indispensable for the transfer of the results gained at this location to other locations where a repository is planned. The rock stresses around the galleries are measured by stress monitors, equipped with seven flat jacks each. They are to be attached to the boreholes either by swelling mortar or by post-injection with resin. The pressure exerted by the stowing materials under the influence of heat up to 100°C is also registered by hydraulic flat jacks which will be fitted to the roof, the walls and the floor of the drifts. Pressure cells of the type "AWID" are to be used in areas with temperatures above 100°C, especially at the surface mock-ups.

Temperature Measurements

Each of the transducers above is accompanied by an electric thermometer. In boreholes additional thermometers under the heaters monitor the temperature field in the very close vicinity of the heat sources down to a depth of 5 m. The thermometers are the resistive gauges PT 100. They have a special coating for usage under elevated temperatures and, possibly, in brine.

Laboratory Program

The behavior of the backfill is of great importance for the safety of a repository. It must be investigated at what time the stowing is capable of taking over the functions of the other technical barriers should they ever be hazarded by corrosion. For this purpose speciment from the same backfilling material as that in the emplacement drifts will be subjected to the same pressures and temperatures which are measured in the test. Subsequent to compaction the development of porosity, permeability and the load bearing capacity is to be measured at different times by this method.

Geophysical Investigations

The observation of the behavior of a storage system consisting of rock mass, gallery, backfilling and containments with both rock mechanic and thermal loads produces many questions which must be answered by geophysical methods.

First there is the problem of changes of the rock mass in which the gallery system is installed. The extent of its

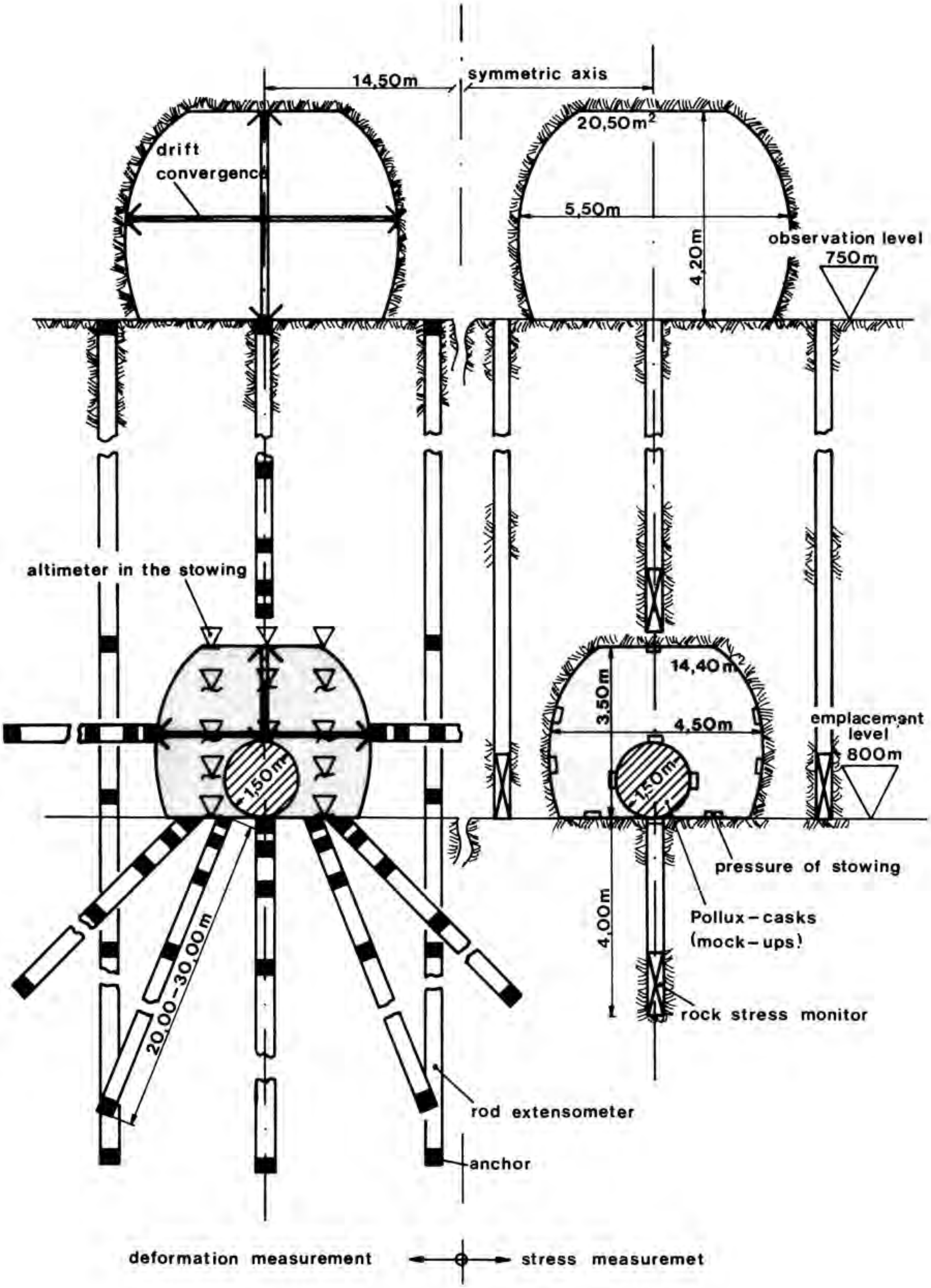


Fig. 2. Diagram of the Geotechnical Instrumentation.

zone of incompetent rock is important in consideration of the safety aspects of radioactive waste deposit. The backfilling of the emplacement galleries has to perform two major tasks; firstly, to stop the loosening as soon as possible and secondly to seal against fluid in case of a fault.

At the beginning both effects (loosening of the rock mass and leakage of the backfilling) lead to a diminuation of safety aspects. After a considerable span of time it is possible that the backfillings better fulfill the requirements of a seal, and after a certain period the effect reaches an optimum. After the settling of this rock mass the formation returns to a safe configuration. The role of thermal sources in these processes is the subject of the investigations.

Microseismicity

Each opening of a cavity in a rock mass produces a stress and strain field in the surroundings. This may be the origin of fractures which are detectable by seismic methods.

In the Asse salt mine there is a special network to detect local seismic events. This network will be expanded to the new location of galleries for the research of seismic activity due to thermomechanical effects. With this surveying system it is possible to locate the seismic focus and to estimate time of origin, energyand length of fracture.

Density

The amount of strain caused by the construction of galleries also leads to a superposition of primary and secondary strain fields which yield strain concentrations at special locations. A change in density of the material is produced at these points. With suitable tools and methods the changes in density could be observed and measured. A well-known method in geophysics is the gravity method.

Subsurface gravity measurements in mines for the investigations of different problems is becoming more and more important. This is due to the development of apparatuses with greater sensitivity. Modern gravity meters reach resolutions of about 200×10^{-9} gal instead of 10×10^{-6} gal by conventionals ($1\ \text{gal} = 1\ \text{cm} \times \text{s}^{-2}$).

Figure 3 shows computed anomalies for a system of two parallel galleries with a 10 m pillar between them. The cross-section of each gallery is 14 m^2 and the length 70 m. The density contrast after the galleries are opened is $\rho = -2.2\ g \cdot cm^{-3}$ (curve 1). When one or both galleries are refilled by salt grit, the contrast changes to $\rho = -0.8\ g \cdot cm^{-3}$ (curves 2 and 3), and after compaction by convergence the last value becomes $\rho = -0.4\ g \cdot cm\text{-}3$ (curve 4). The observation profile is found 50 m above the gallery system (the loosening is not taken into account).

The density changes, especially of the backfilling, are controlled by gamma-gamma-density log. This tool furnishes a log of back-scattered gamma radiation which is a function of formation density. The method is well-known in applied geophysics. The accurately calibrated density logger allowed a resolution of $0.03\ g \cdot cm^{-3}$.

The density survey of the backfilling takes place in two boreholes from 50 m above the gallery system through the backfilling. The part of the borehole which runs through the filling is fitted with a casing. The effect of the casing due to the density readings must be exactly known.

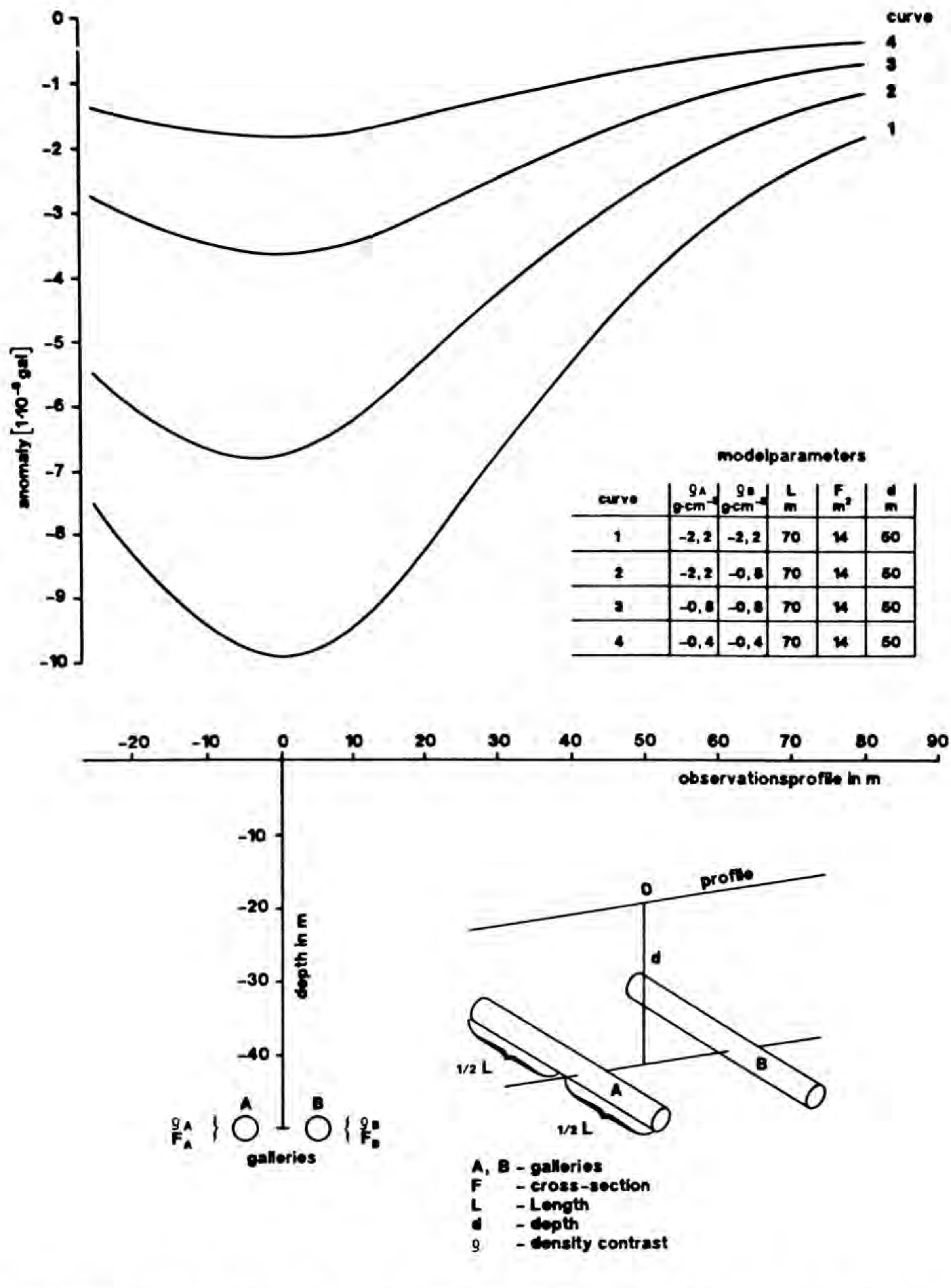
The observation of gamma-ray estimated densities are carried out during the entire experiment.

Compaction

The subject of the physical behavior of the backfilling is not only the amount of density but also the compaction, which depends on physicochemical processes.

At the beginning of the experiment the backfilling is a loose material, as defined by soil mechanics. This means that there are only frictional forces between the particles of the material. By convergence, the density as well as the seismic velocities increase. But the absorption of seismic energy decreases because of cohesion.

Seismic sources and receivers are tuned on the ultrasonic frequency range. By the research of density, seismic velocities and absorption of seismic energy of a distinct backfilling volume, it is hoped to find a description of the transition from loose material to the formation of a bonded material.



curve	ϱ_A g·cm^{-3}	ϱ_B g·cm^{-3}	L m	F m^2	d m
1	-2,2	-2,2	70	14	50
2	-2,2	-0,8	70	14	50
3	-0,8	-0,8	70	14	50
4	-0,4	-0,4	70	14	50

Fig. 3. Computed Gravity Anomalies of a System of Two Parallel Galleries for Different Phases of Backfilling.