CONTAINERLESS DISPOSAL AND IN SITU SOLIDIFICATION OF WASTE IN UNDERGROUND CAVITIES ASPECTS OF MINING TECHNOLOGY AND ENGINEERING

Th. Meyer, Ch. Starke and M.W. Schmidt
GSF Institut fur Tieflagerund
Theodor-Heuss-Str. 4,
D-3300 Braunschweig, F.R.G.

ABSTRACT

Besides the disposal of low (LLW) and intermediate-level (MLW) radioactive wastes, emplaced in containers into chambers and drifts, a research programme is being conducted under the auspices of the Kernforschungszentrum Karlsruhe (KfK/PWA) which is concerned with the containerless storage of waste filled directly via boreholes from above ground into caverns. The basic idea is to develop a safe long-term disposal method for LLW and MLW into caverns and to prevent any nuclides from reaching the biosphere. This presentation gives an insight into the investigations regarding the dimension and construction of caverns, their connection to above ground and the sealing technique of filled caverns.

INTRODUCTION

Currently there are different concepts worldwide for the final disposal of waste. Various geological formations are considered as suitable for repositories in the deep geological underground.

During recent years the choice of rock salt formations has shown a number of advantages among other locations. In the Fed. Rep. of Germany the current Research and Development activities favor the utilization of existing north German salt structures.

Besides various already developed and tested storage techniques a different concept for the containers disposal and in situ solidification of waste has been developed. R.H. Kraemer and R.H. Kroebel [1] have presented a comprehensive overview of the "In-situ-Solidification Technique for Waste Disposal in Underground Caverns". The main procedural steps are shown in Table I.

TABLE I

Main Procedural Steps of the Containerless Disposal and in Situ Solidification

- MINING OF THE CAVERNS
- GRANULATION OF MLW/LLW
- TRANSPORTATION OF THE GRANULES TO THE MIXING STATION
- MIXING OF GRANULES WITH CEMENT/WATER SUSPENSION
- PIPING OF THE MIXTURE THROUGH A VERTICAL TUBE
- IN SITU SOLIDIFICATION TO A MONOLITHIC BLOCK
- CONSTRUCTION OF THE CAVERN SEAL

The main emphasis of this paper is focused on the mining and sealing constructions of caverns.

The final repositories for MLW and LLW in caverns should be constructed in geological formations whose geological history and structure is known. A virginal part in the center of the salt dome should be selected. For the containerless disposal and in situ solidification two cavern constructions and their connection or access to the surface facilities are feasible (Fig. 1):

- caverns connected via boreholes to the surface
- caverns connected to an accessible mine.

DIMENSIONING AND CONFIGURATION OF CAVERNS

As a consequence of its good rock mechanical characteristics rock salt is particularly well-suited for the construction of large cavities. The dimensioning of the cavern volume was adjusted according to the expected waste production. At the beginning of the project an annual waste volume of approx. 15.000 m^3 was assumed. An operating period of 15 years was taken as basic consideration. Taking these data into consideration, a cavern volume of 225.000 m3 must be provided. Due to rock mechanical and resulting

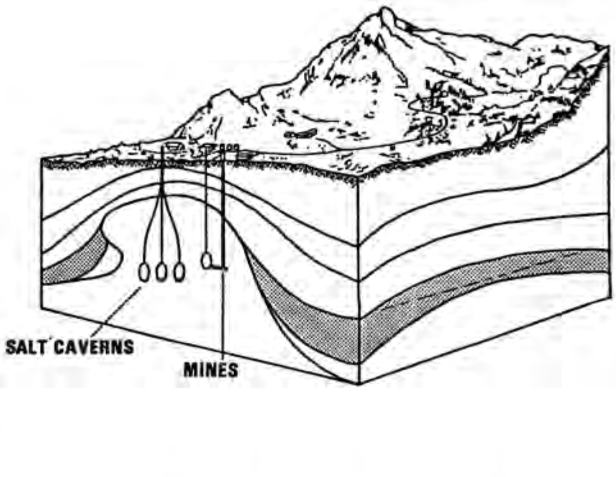

Fig. 1. Storage Possibilities.

TABLE II

Dimensioning and Configuration of Cavern

Form
- Slim rotational ellipsoid or
- Cylinder with added conical stump ends

Dimensions
- Height : 80 - 100 m
- Diameter : 30 - 50 m
- Volume : ~75000 m^3

Configuration
- Distance from caprock : < 170 m
- Distance between cavern : ~ 220 m
- Distance between drift and caverns : ~ 150 m (standard mining techniques)

stability investigations this particular cavity volume cannot be stable as a single covern without internal pressure at a depth of approx. 1000m. Consequently three caverns are required which are connected to one surface mixing and dosing facility. The resulting cavern volume was determined to be 75.000 m^3. To optimize the form, the dimension and the configuration of the cavern with one another, numerous calculation programes were carried out. The detailed cavern specifications are summarized in Table II.

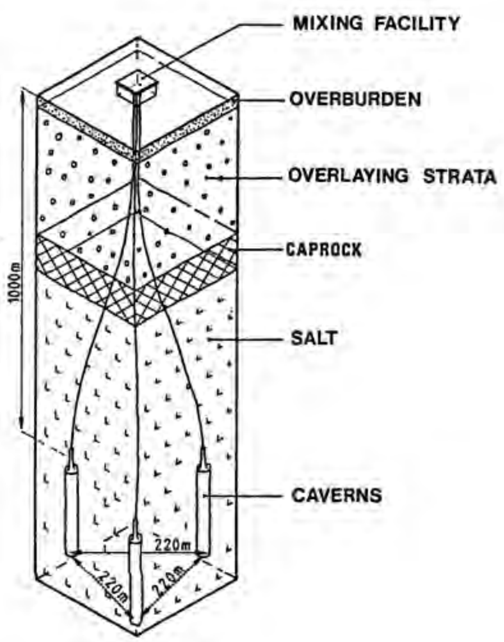

Fig. 2. Configuration of Caverns.

Fig. 2 shows the configuration of the caverns and its connection to above ground.

CAVERN CONNECTION TO ABOVE GROUND

The main criteria and aspects of the drilling concept [5] for the access borehole can be summarized as follows:

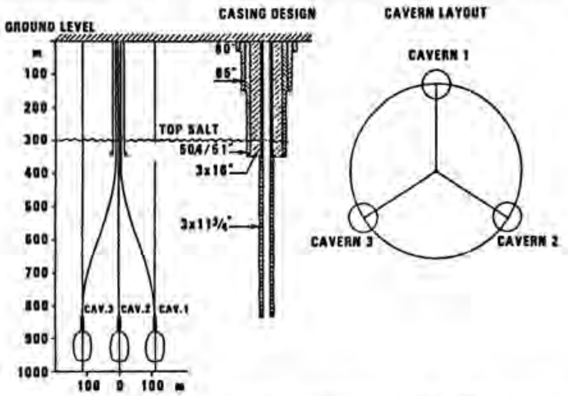

Fig. 3. Cavern Construction Via One Large Borehole.

- Minimizing penetrations of the salt horizon, which are carried out with two central casing strings
- Connection of three caverns to one mixing plant, each cavern requiring a separate access
- Minimizing the diameter of the casings
- By using gravity or pumping haulage the flowable mixture of granulate, cement and water is fed into the cavern via additional vertical pipes with an inner diameter of 60 mm

In this concept the boreholes are feasible with a final casing of 11 3/4".

In the first concept, as shown in Fig. 3, the salt horizon is penetrated individually. A vertical borehole is drilled to approx. 60 m from an 80" conductor pipe and cased with a 65" anchor casing. A 51" casing string is extended down to a

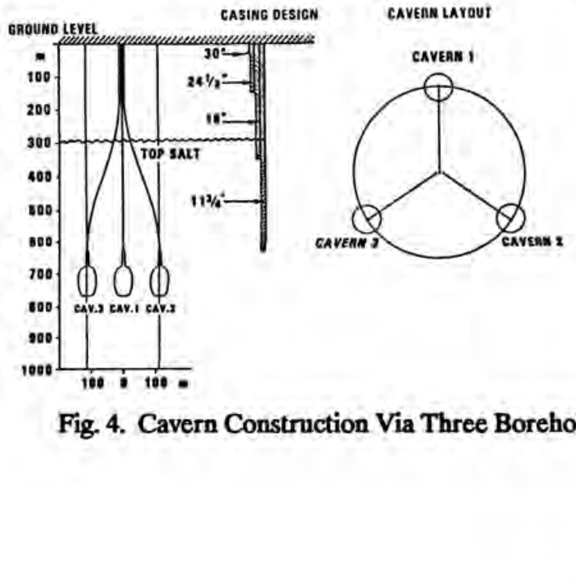

Fig. 4. Cavern Construction Via Three Boreholes.

level 50 m below the salt caprock and serves as a conductor could be lowered. All casings are cemented to the surface.

In the second concept three individual boreholes are drilled from the surface with only a small mutual separation (5 10m). Fig. 4 shows the drilling concept and the casing design.

The safety hazard of a leak via the cementation of three thin boreholes is slightly lower than that of a large diameter borehole. For this reason and because of lower costs, the alternative of three separate boreholes is taken as basis for the realization of the drilling concept.

CAVERN MINING

The production of cavities in suitable rock salt can be achieved by different mining techniques, such as

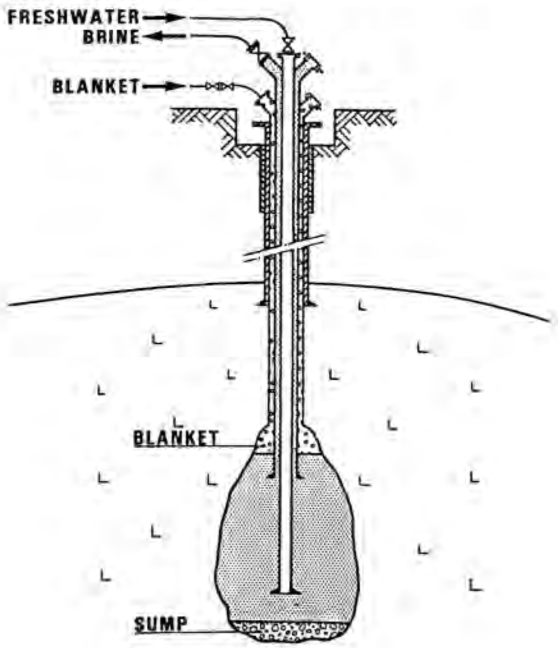

Fig. 5. Schematic Diagram Overhand Stopping From Below.

- conventional mining techniques
- solution mining techniques

Conventional Mining

In order to construct cavities using conventional mining methods, the cavern has to be excavated via access drifts and shafts by drilling and blasting or by using a continuous miner [6]. In additional, it is necessary to link the cavern to the surface prior to construction.

In principle two cavern excavation methods are possible:

- underhand stopping technique
- overhand stopping technique
- The overhand method is shown in Fig. 5.

For rock mechanical and economic reasons the following variant is favored: mining the rock from the bottom to the top, and subsequently hauling the broken material from the top to the bottom reduces the open lifetime of the cavern and permits the broken material to expert supporting pressure onto the rock for as long as possible. Conventional mining of caverns by one of the above mentioned methods is a technique which has been proven for the first time in salt rock in the Asse mine [7].

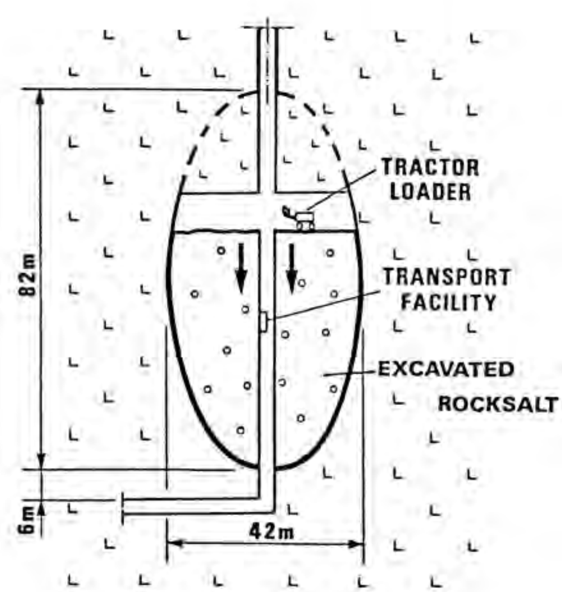

Fig. 6. Schematic Diagram of jDirect Leaching Process.

Solution Mining

The construction of the large cavities, in suitable rock salt formations by dissolution of salt using water is a technique which has been employed with great success for several decades. This technique was originally used for the production of salt, but in the last years it has become standard practice for cavities to store liquid and gaseous-phase hydrocarbons.

The schematic diagram of a leaching process [5] is shown in Fig. 6.

A salt cavern is "solution mined" by drilling a hole to the rock salt strata. A freely suspended pipe string is set and circulating fresh or low-saline water is introduced to dissolve the salt. After saturation of the water the brine is transferred to the surface. The borehole enlarges to a cavity by continuous inflow. The blanket, which is injected via the outer annulus into the borehole, prevents the uncontrolled dissolution of the salt in the area of the cavern top. In the last phase of the leaching process the blanket level is lifted in several steps to produce an approximately half-elliptical cavern roof. The accumulated insoluble material, which consists mainly of clays and anhydrites, sediments into the sump.

During the leaching process the cavern form is monitored by carrying out control surveys using, e.g., an echolog. When leaching is completed, the borehole and the cavern are subjected to a pressure test to check the tightness of the cavern, especially of the casing cementation. Prior to filling the cavern, the brine has to be removed in order to prevent any contact with the waste. For such a draining process there are basically two technical methods available:

- Drainage by means of submersible pumps installed in the cavern.
- Drainage of brine by displacement with compressed gas.

The principle of brine displacement with gas is illustrated in Fig. 7.

A pipe string has been lowered to a level just above the sump sediments. The brine can be transported to the surface by means of compressed air (approx. 120 bar).

Using the techniques mentioned, it is possible to dewater a leached cavern to a degree which is required for a conventional hydrocarbon cavern. In case of the final storage of MLW/LLW all residual brine as well as the brine in the pores of the sediment in the sump must be removed.

Hence a pipe has to be drilled or flushed into the cavern sump and a filter tube has to be installed. The sump dewatering can be carried out with compressed gas or a submersible rotary pump. The principal details of the method using a pump are shown in Fig. 8. Employing these methods it is possible to dewater a leached cavern leaving only small amounts of residual water in the sump.

GEOMECHANICAL STABILITY OF THE FILLED CAVERN

Drilling of the borehole and leaching of the required cavern volume is safely controllable from a technical point of view.

Due to the good rock mechanical characteristics of rock salt the cavern has a guaranteed stability. During the

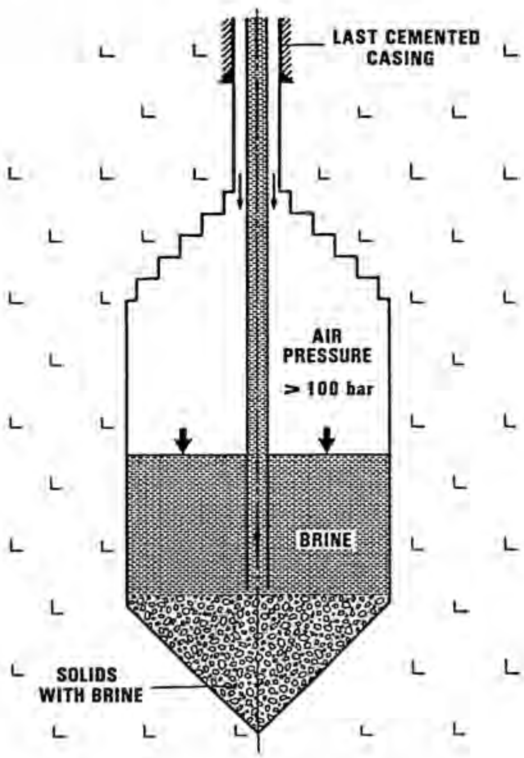

Fig. 7. Dewatering of Cavern Using Gas.

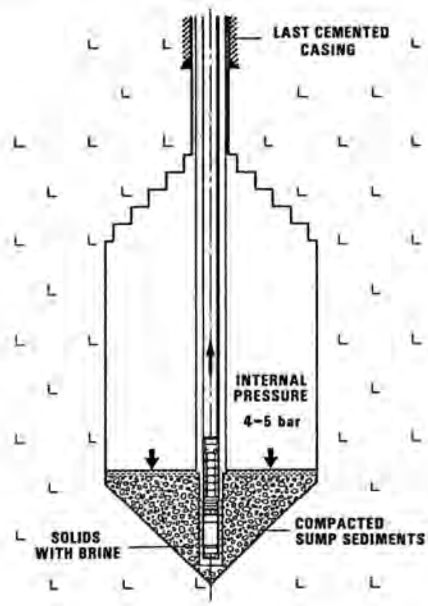

Fig. 8. Sump Dewatering.

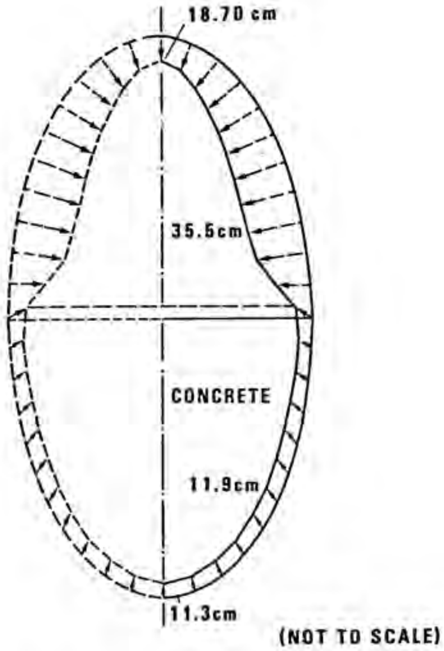

Fig. 9. Cavern Wall Displacement of a Half-Filled Cavern.

operational phase and prior to filling, the deformation around the cavern is high. After complete filling of the cavern and the ensuing solidification of the MLW/LLW-cement slurry, the disposed waste displays a behavior almost compatible to the rock-mechanical conditions of the host rock. The solidified waste effects a favorable supporting pressure on the converging host rock.

Geotechnical in situ observations in the empty conventionally mined Asse prototype cavern show a continually decreasing convergence rate over ten years. Comparable FEM-calculations of an empty, a half filled and a completely filled cavern (cf. Fig.9) have shown the decrease of convergence of the cavern wall as well [7].

Fig. 10 shows the calculated displacement rate of a point at the cavern top during a period of 1400 days. After 700 days a sudden filling of the cavern was assumed. The results of the calculation show an immediate decrease of the displacement rate after the complete filling of the cavern. After solidification of the MLW/LLW cement slurry of a monolithic block the displacement reaches its limiting value. A complete and tight enclosure of the waste is guaranteed.

SEALING OF CAVERNS AND ACCESS BOREHOLE

Seals are required to prevent or retard migration of radionuclides from the repository to the biosphere through the excavations used for the access to the repository. In order to achieve this primary function the individual seal components should have other supporting functions, such as prevention or retardation of ground waste flow into the repository.

Fig. 11 shows schematically the sealing of a solution and a conventionally mined cavern. Due to the tunnels from the

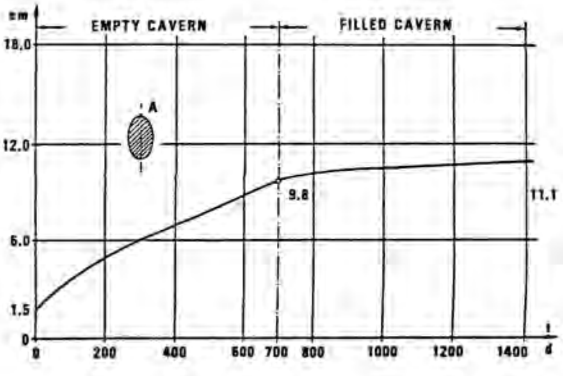

Fig. 10. Displacement of Point a At Cavern Top (According to DUDDECK).

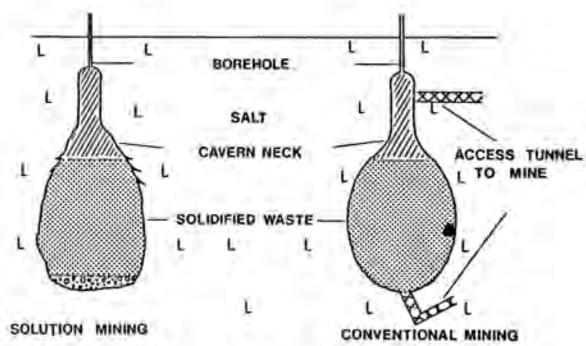

Fig. 11. Sealing of Filled Caverns.

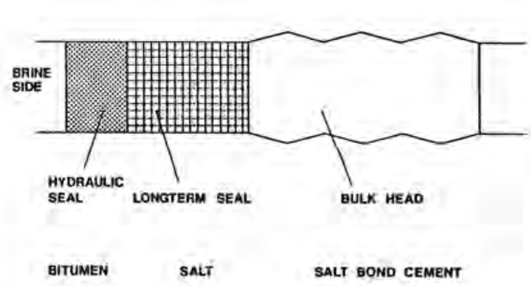

Fig. 12. Schematic Seal of Access Tunnel.

accessible mine to the cavern, more than one opening of the conventionally mined cavern has to be sealed.

In principle the sealing operation can be described as follows:

- Sealing of access tunnels to the mine (conventionally mined cavern)
- Sealing of cavern roof and cavern neck
- Sealing of access borehole from above ground to the cavern

The access tunnels from the mine to the cavern zone have to be securely and tightly sealed prior to filling operations. Experience has shown that for drifts or tunnels with large cross-sections plug type seals or dams are well suited. A schematic diagram of such a sealing system with its individual sections is shown in Fig. 12.

With this multiple-component sealing technique consisting of various different components, an elastic, water and gastight long term safe seal can be achieved. Each of the sealing materials mentioned is needed for a specific function (Table III).

TABLE III

Sealing Materials and Their Functions

Sealing component	Sealing material	Function
Bulkhead	salt/cement bond	mechanical abutment
Lon g term seal	crushed salt, precompacted salt blocks	long term stability
Hydraulic seal	bitumen	elasticity, immediate brine - and gastightness

Furthermore every sealing component mentioned has to be tested for its chemical, geomechanical and mineralogical compatibility with its host rock.

In order to prevent radioactive materials from reaching the biosphere via the cavern neck and the access borehole of a solution as well as conventionally mined cavern, a multiple-component seal has to be constructed (cf. Fig. 13).

It is necessary to provide a permanently tight, maintenance-free cavern seal in the area of the cavern roof and the casing shoe of the last cemented casing. The filling and sealing operations of this part consists of the following procedural steps:

- Filling the cavern nearly up to the cavern roof with waste (pellets and cement slurry)
- Filling the residual volume of the cavern with non-active cement slurry
- Filling the lower uncased 50 100 m of the access borehole of the cavern neck with an interbedding of cement, bitumen and salt of an individual *thickness* of 5 10 m
- Filling the remaining in part of the borehole to above ground with cement

CONCLUSIONS

The in situ solidifications concept, as developed during the past years, represents another type of disposal concept as compared to the drum disposal technique which is already demonstrated in the abandoned Asse salt mine. Significant advantages with respect to a safe operation and economic benefit led to the previous Research and Development efforts which have been directed towards this project since 1976.

Upon comparing this disposal technique to the drum disposal technique it becomes apparent that less open cavity volume is required. Furthermore, the stability requirements for large man-operated mines will be much higher than for a cavern which is mined by the solution mining technique.

After complete filling of the cavern with radioactive or chemical wastes the entire solidified monolith forms a block which has a similar rock-mechanical behavior as the host rock.

The filled cavern restabilizes the geological strata and stops convergence movements. After the operational phase

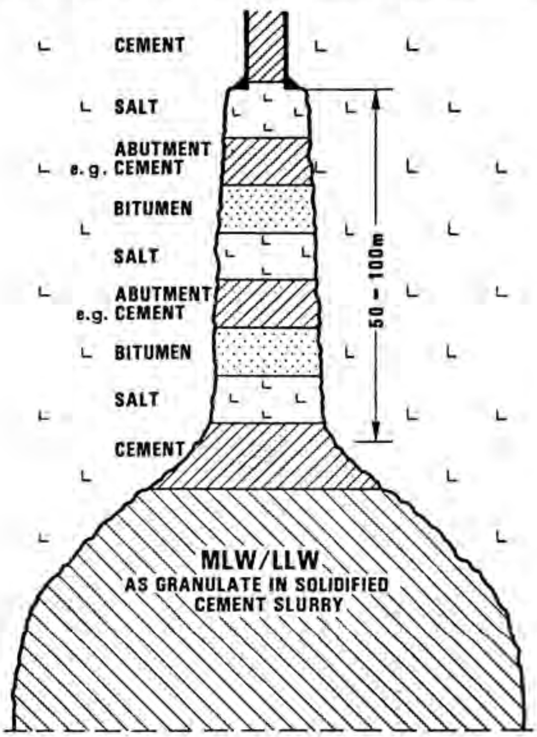

Fig. 13. Principle of a Final Seal for a Filled Cavern.

a filled, solidified and sealed cavern needs a similar safety level in chambers, the access tunnels have to be sealed by dams of great dimensions.

During the previous years experiments and investigations have shown that this concept is technically feasible for radioactive as well as for chemical wastes and has substantial advantages over the other methods mentioned.

REFERENCES

1. R.H. KRAEMER, R.H. KROEBEL, "Insitu Solidification Technique for Waste Disposal in Underground Caverns", Proceedings of this Symposium (1983)
2. P. QUAST, M.W. SCHMIDT, "Disposal of Medium and Low-Level Radioactive Waste (MLW/LLW) in Leached Caverns", Sixth Int. Symp. on Salt, Vol. II, Toronto, Ont., Canada (1983)
3. P. QUAST, E. HAWICHENBRAUCK, M.W. SCHMIDT, "Engineering, Geological and Safety Technological Aspects for the Final Disposal of In-situ-consolidated Radioactive Waste in Hard Rock and Salt Formations", Bull. of the Int. Assoc. of Engineering Geology, No. 34, pp. 73 85 (1986)
4. W. RAAB, C. FROHN, M.W. SCHMIDT "Stability and Construction of Caverns for the Disposal of Cemented Low-and Medium-Level Wastes", 5th Int. Symp. on the Scientific Basis for Radioactive Waste Management, pp. 879 888 (1982)
5. Kavernen Bau- und Betriebs-GmbH, "Herstellung von Kavernen uber abgelenkte Bohrungen", unpublished (1985)
6. Thyssen-Schachtbau GmbH "Bergmannische Erstellungen von Kavernen", unpublished (1985)
7. M.W. SHCIMIDT, H. KOLDITZ, G. STAUPENDAHL, K. THEILEMANN, "Bau einer Prototyp-Kavernenanlage im ehemaligen Steinslazbergwerk Asse zur Durchfuhrung von Forschungs- und Entwicklungsaufgaben auf dem Gebiet der Endlagerung radioaktiver Abfallstoffe", Rock Mechanics, Suppl. 8, pp. 249 262 (1979)
8. H. DUDDECK, NIPP, "Finite-Elemente-Berechnungen uber das statische Verhalten von MLW/LLW-Einlargerungs-Kavernen mit 75000 m3 Volumen", Bericht des Instituts fur Statik der TU Braunschweig (unpublished)