IN SITU-EXPERIMENTS ON THE DISPOSAL OF HIGH-LEVEL RADIOACTIVE WASTES (HAW) AT THE ASSE SALT MINE FEDERAL REPUBLIC OF GERMANY

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ABSTRACT

Deep geological salt formations are considered as being the most suitable medium for the disposal of radioactive wastes in the Federal Republic of Germany (FRG).

In order to develop and to prove the necessary disposal techniques, the Asse Salt Mine in the northern part of Germany is being used as a national R&D facility for the execution of representative in situ-tests. Besides the test-wise disposal of low- and medium-level radioactive waste, a series of in situ experiments was performed on the disposal of high-level radioactive waste (HAW). The so-called HAW-project which is being performed from 1983 through 1994 will be the most important pilot test for the HAW repository in the FRG. During this experiment, 30 vitrified high-level radioactive heat and radiation sources produced by Battelle Pacific Northwest Laboratories (PNL) will be emplaced in six underground boreholes. The duration of testing will be approximately five years. In addition to the investigations of the interactions of the heat and radiation sources and the host rock, a complete handling system for HAW-canisters is being developed and proved.

INTRODUCTION

The concept of the Federal Republic of Germany for the disposal of HAW is based on reprocessing of spent fuel elements and on vitrification of high-level liquid waste. The resulting heat-producing waste canisters will be disposed of in deep vertical boreholes drilled into the salt formation of an underground repository. The salt dome of Gorleben, located in the northern part of the country, is currently being investigated for its suitability to host a repository for all types of radioactive wastes. The Asse Salt Mine operated by the GSF Institut fur Tieflagerung (IfT) is serving as an R&D facility for the performance of the necessary representative in situ tests.

From 1967 until 1978, about 125,000 containers with low-level waste and about 1,300 200-liter drums with medium-level waste were successfully disposed of in this mine. Already in the late sixties, GSF increased its R&D activities concerning the disposal of high-level radioactive waste (HAW).

HAW is characterized by its high gamma radiation and heat production because of the absorption of alpha and beta radiation in the glass matrix. After vitrification, the waste products will have a heat power of about 17 watts/liter. This heat will be delivered to the surrounding rock salt formation thereby increasing its temperature. The temperature increase leads to a measurable changes of the mechanical properties of rock salt.

The naturally-occurring deformation rates of the salt are accelerated. Because of the elastic-viscoplastic material behavior the salt at the borehole wall will creep onto the waste canister surface. Thereby, the waste is hermetically sealed and the possible release of radionuclides is significantly reduced because possible fractures and fissures in the salt are closed and sealed by this mechanism. Also, the physico-chemical properties of rock salt are changed by the temperature increase. Natural rock salt normally contains very small amounts of liquids (on the average, less than 0.01%) in the form of crystalline water of accessory minerals like polyhalite ($2CaSO_4 \cdot x K_2SO_4 \cdot x MgSO_4 \cdot x 2H_2O$) and kieserite ($MgSO_4 \cdot x 2H_2O$) and adsorbed water molecules on the grain boundaries. Also brine inclusions of some microns in diameter are known to occur in rock salt. The liquids may be released due to the temperature increase into the disposal boreholes. Corrosion of canister materials is therefore another issue to be resolved regarding the disposal of HAW in rock salt.

The gamma radiation of HAW will also have an impact on the host rock. The traces of liquids as well as accessory minerals might be decomposed radiolytically. Also, the halite matrix (NaCl) might be decomposed radiolytically whereby colloidal sodium and gaseous chlorine could be generated.

In order to investigate the interaction of HAW canisters with the surrounding host rock, a series of in situ experiments was and is being performed in the Asse Salt Mine. The first in situ test was already started in 1968. Tests No. 1 through 4 were performed to investigate the thermal and mechanical behavior of rock salt, especially the heat distribution in an underground repository.

TEMPERATURE TEST NO. 5

During Temperature Test No. 5, the thermal stability of natural rock salt containing accessory minerals like polyhalite was investigated (1). Figure 1 shows the setup for this test. An electrical heater, three meters long, was placed in a seven-meter-deep horizontal borehole with a diameter of 0.28 m. The electrical power input varied from 2 to 6 kW. I this case, the salt was heated up step-wise to a maximum temperature of 270° C. It could be confirmed what has been found in the laboratory before (2); namely that polyhalite starts significantly to decompose only at temperatures higher than 230 °C. In consequence, one conclusion of this test was that the maximum temperature in a salt repository should not be higher than 200° C. Figure 2 shows the photo of a think section containing a decomposed polyhalite

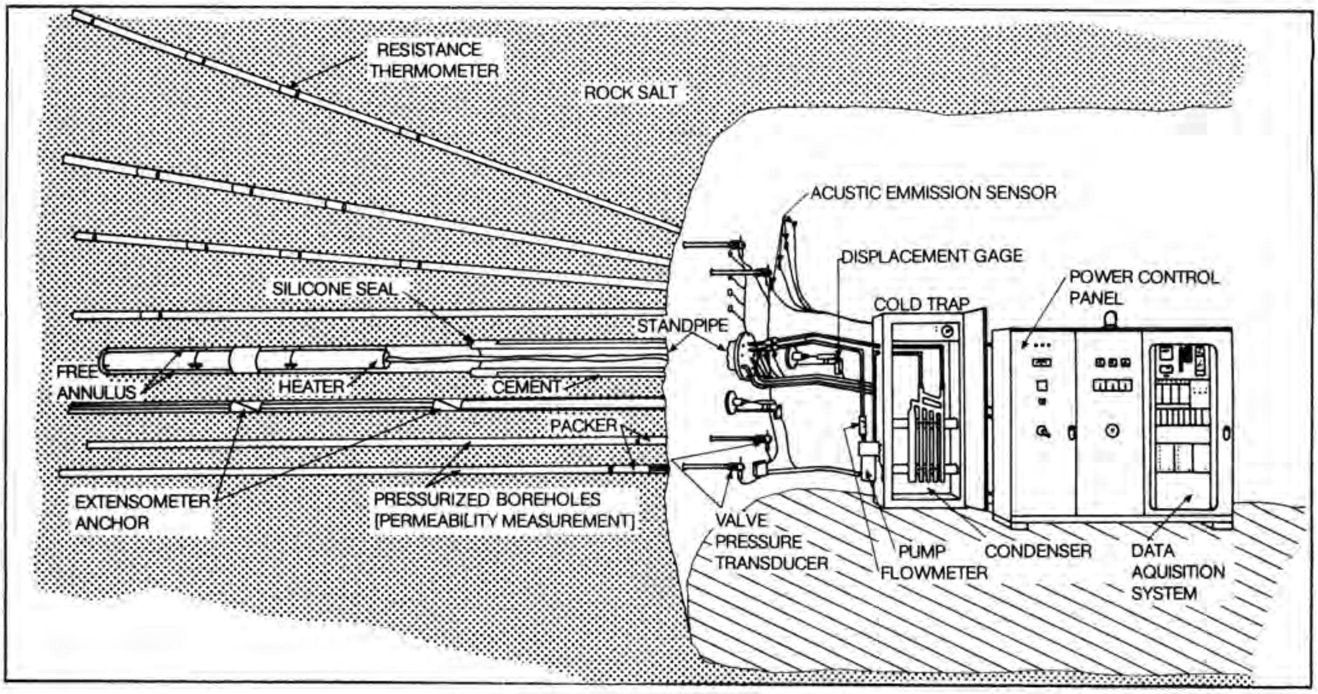

Fig. 1. Set up of Temperature Test No. 5 at the Asse Salt Mine.

Fig. 2. Thermally Decomposed Polyhalite Crystal.

crystal. The sample was taken from a salt portion heated up to temperatures higher than 230° C.

BRINE MIGRATION TEST

In order to investigate the synergistic impact of heat release and ionizing radiation, the joint US/FRG Brine Migration Test (BMT) was performed at the Asse Salt Mine from 1983 through 1985. This HAW simulation experiment involved the simultaneous emplacement of electrical heaters and cobalt-60 radiation sources in rock salt. The underground test field consisted of four individual test sites. At two of them the disposal of HAW was simulated by only electrical heater in boreholes while at the other two test sites both electrical heaters and cobalt-60 sources were emplaced. Detailed information about data, results, and conclusions of the BMT are contained in the final report of the project (3). Figure 3 shows a typical test site of the BMT. Around the central borehole containing the main heater (at Test Site No. 3 and 4 also the cobalt-60 sources), eight guard heaters were installed at 1.5 m distance to the central borehole axis. The heater midplane was 4.57 m below the floor. The length of the main heater and the cobalt-60 sources was 2 m. The total electrical power at each test site was 10 kW in order to obtain a maximum salt temperature of 210 °C on the borehole wall at the heated midplane and a temperature gradient of 3 C/cm. Each cobalt-60 source had an initial activity of 18,000 curies. Heating lasted for about two years at the radioactive sites. In order to resolve the issues of rock mass/waste package interaction, temperature field, brine release into the heater boreholes, borehole gas pressure and composition, as well as rock mass stresses and displacements were monitored during the test. For the validation of computer codes predictions the acquired data were compared to calculated results.

With respect to brine release into the heated boreholes, it was found that KNUDSEN-diffusion is the predominant brine migration mechanism under the conditions at Asse. The velocity of water vapor in case of KNUDSEN-diffusion is proportional to the water vapor pressure gradient in the salt porosity and is given by Eq. 1.

$$v = -c_K \frac{\sqrt{T}}{P_v} \nabla P_v \qquad \text{Eq. 1.}$$

with

v = velocity of water vapour (cm/sec)

c_K = Knudsen factor ($cm^2/\sqrt{K} \cdot sec$)

∇P_v = water vapour pressure gradient (bar/cm)

T = absolute temperature (K).

The calculational model chosen is an evaporation front model assuming that only brine adsorbed on the grain boundaries contributes to the released water. Also, thermal expansion of this brine is considered to increase the water release rates. In the calculation, an initial water content of the rock salt of 0.01 wgt% was considered. The porosity of

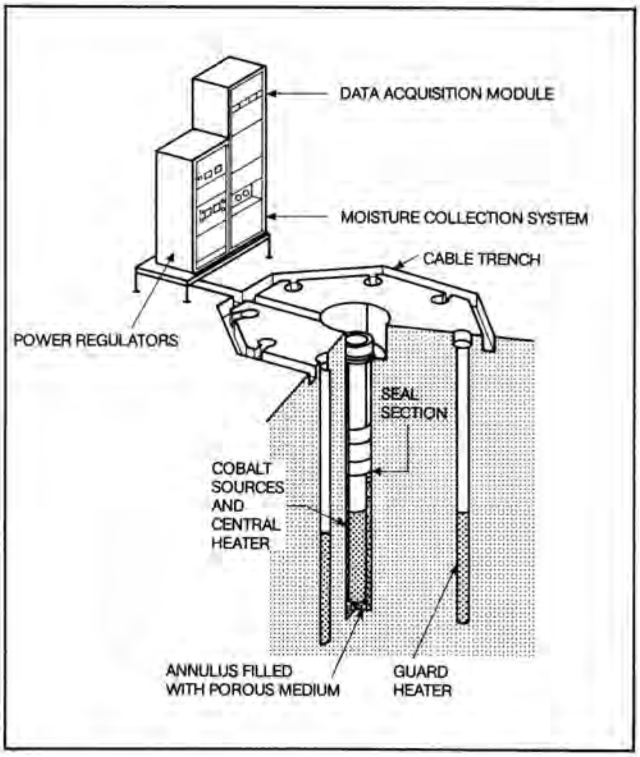

Fig. 3. Typical Test Site of the Asse Brine Migragion Test.

the salt was assumed to be 0.175 • $\times 10^{-3}$ and the Knudsen factor 2.53 • $\times 10^{-13}$ $cm^2/\sqrt{K} \times \cdot$ sec. Figure 4 compares curves of measured and calculated amounts of water accumulated in the heated boreholes.

With regard to radiolytical gas generation, the experimental results showed that small amounts of hydrogen (less than 2 vol.-% of the borehole atmosphere) were mainly produced by corrosion of materials and not by radiolysis.

HAW TEST DISPOSAL

The present situation in the field of in-situ-tests for the disposal of HAW is characterized by the fact that no real 1:1-scale pilot test has been performed so far. Construction and operation of pilot plants, however, are generally considered to achieve safety and to find weak points in the development of complex engineering systems with respect to their large-scale industrial application.

The emplacement of spent MTR fuel elements in salt, experimentally conducted in a very early stage of the overall repository research (1965 1967, US Project Salt Vault, Lyons Mine, Kansas), was used for studying the thermal, thermomechanical, and radiolytical issues (4). It was carried out, however, under conditions that agreed only very limitedly with the current repository planning. The test phase of two years corresponded to the average duration of former heater tests.

The Brine Migration Test represented a significant preparatory step towards the experimental emplacement of HAW in the Asse Salt Mine. Nevertheless, the radiation

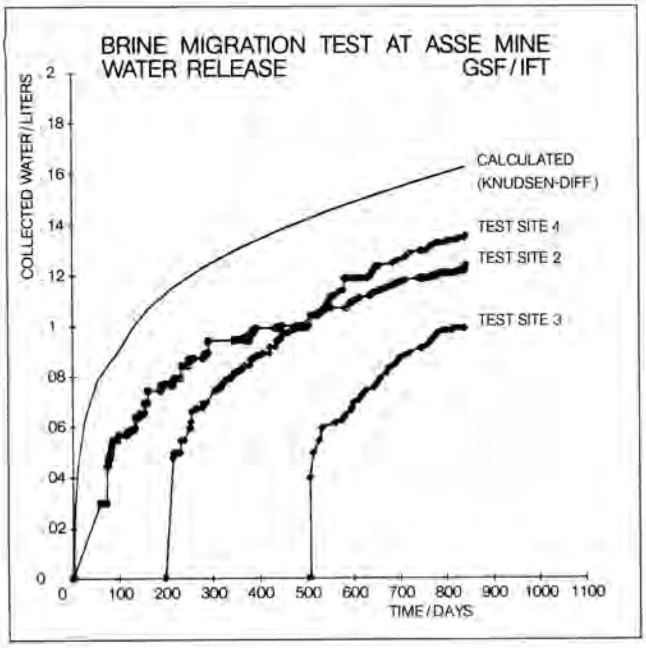

Fig. 4. Comparison of Measured and Calculated Water Release Data of the Asse Brine Migration Test.

dose adsorbed on the borehole wall due to the use of cobalt-60 sources during the test duration of two years is one to two orders of magnitude below the conditions to be expected in a HAW-repository.

Therefore, the HAW test disposal with a duration of five years will be performed in the Asse Salt Mine. This test will involve the emplacement of thirty vitrified high-level radioactive heat and radiation sources in six underground boreholes. These sources were produced by Battelle Pacific Northwest Laboratories (PNL), Richland, Washington, within the frame of the US/German contract on "technical exchange and collaboration in the handling and disposal of radioactive wastes."

Heat and Radiation Sources

In order to obtain the respective gamma radiation and heat output of future high-level waste from reprocessing the radiation sources are doped with radioactive cesium-137 and strontium-90. The fission products responsible for most of the radiation and heat of real HAW during the first 200 years after emplacement in the repository, are represented by the exclusive use of the above nuclides, such that long-lived alpha emitters can be dispensed with. Due to the special mode of producing the glass blocks, neither actinides nor fissile material like U-235 or Pu-239 are contained in the heat and radiation sources.

It has been agreed to fabricate differently endowed sources to obtain the following sets of radioactive canisters:

- Set 1: Ten canisters doped with Cs-137 and Sr-90 with a surface dose rate of 5.0×10^5 R/h and a heat power of 2,065 watts.
- Set 2: Ten canisters doped with Cs-137 and Sr-90 with a surface dose rate of 5.0×10^5 R/h and a heat power of 1,680 watts.
- Set 3: Ten canisters doped with Sr-90 only which leads to a negligible surface dose rate but also a heat power of 1,680 watts.

Underground Test Field

The configuration and dimensions of the underground test field are shown in Fig. 5. The test field consists of a set of eight boreholes, each 15 m deep, located in two parallel galleries (A and B) at the 800 m level. Two boreholes in each gallery will have a maximum salt temperature of 250 C and two of 200° C.

Fig. 5. Layout of the HAW Test Field on the 800 m Level and Arrangement of the Emplacement Boreholes.

Two of the 250° C boreholes (A1 and B1) will be heated electrically only and each of the two others (A2 and B2) will be charged with five radioactive canisters of set 1. Two of the 200° C boreholes (A4 and B4) will be only heated by emplacing five Sr-90 canisters of set 3 and each of the remaining two boreholes (A3 and B3) will be charged with five canisters of set 2. In this manner, it is possible to investigate the impact of gamma radiation and of heat release at different maximum salt temperatures.

Because of special licensing requirements at the Asse Salt Mine, the radioactive canisters have to be retrieved at the termination of the in-situ experiment. Therefore, the boreholes are lined with high-strength steel tubes (Fig. 6).

Emplacement Boreholes

Those boreholes having the same maximum temperature and being equipped with the same type of canister are differentiated as types A and B. In the boreholes of type A, the annulus between liner and borehole wall will be backfilled with a porous medium to avoid the borehole wall creeping onto the liner and for maintaining a pathway for released water and gas components. In the boreholes of type B, the annulus will not be backfilled so that the salt is permitted to creep onto the liner. Hereby, the influence of a possibly nearly gas-tight contact between the rock mass and the waste canisters can be investigated with regard to the release behavior of water and gases.

In-situ Measurements

Most of the in-situ experiments performed in an advanced stage of underground testing are combined experiments. An objective of such experiments often is to answer more than one question. Therefore, the applied instrumentation covers a fairly wide range. The investigations during testing include the measurement of radiation dose and dose rate, temperature, rock mass stresses and displacements. Radiolytical decomposition of natural rock salt is an issue that will be investigated, too.

Handling System for HAW Canisters

The development and testing of a handling system for

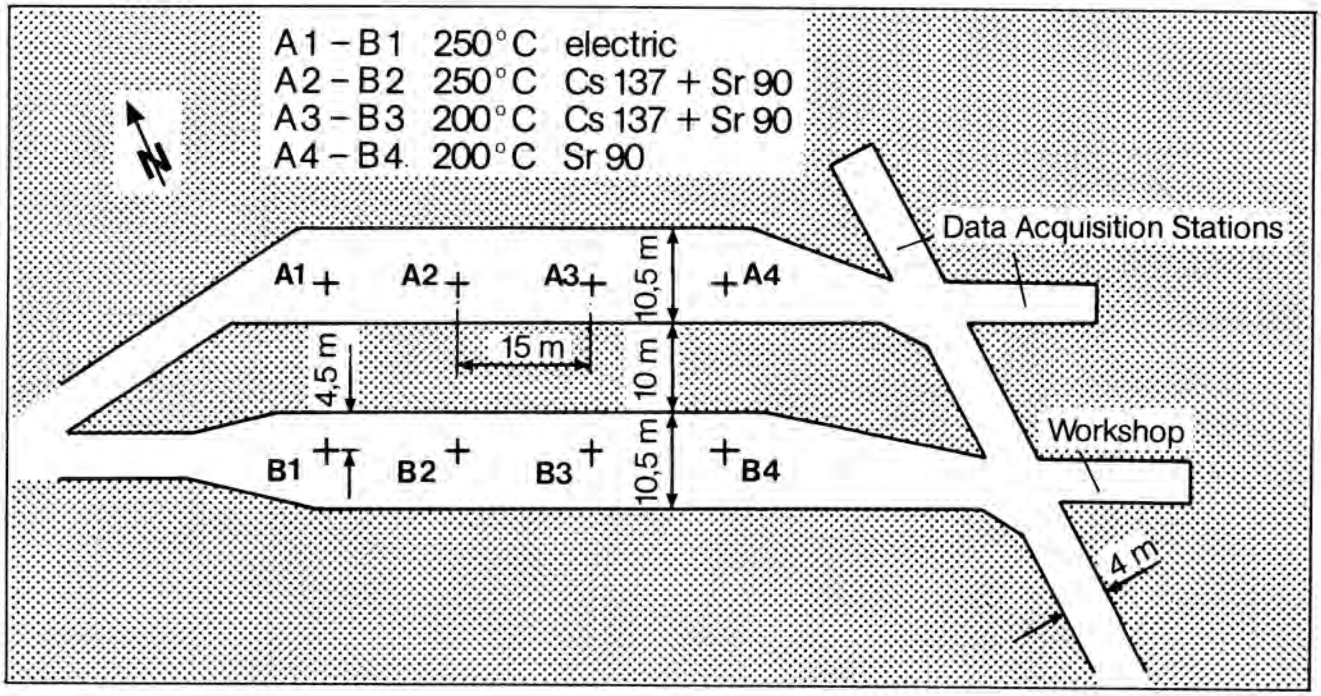

Fig. 5. Layout of the HAW Test Field on the 800 m Level and Arrangement of the Emplacement Boreholes.

transportation and emplacement of HAW canisters is an additional important objective of the HAW project.

Though equipment to handle radioactive components is to be found in various nuclear plants, it cannot be transferred to the conditions of routine operations in an underground repository. Consequently, one of the objectives of the experiment is the development of a complete handling system and its testing under actual operational conditions. The system for the HAW test disposal at Asse is shown in Figure 7. The handling components include:

- Multiple Transport CAsks (MTC) Castor GSF 5
- Above-Ground Receiving and Transfer Station
- Single Transport Cask Asse TB 1
- Underground Transport Vehicle
- Borehole Slider
- Disposal Machine

A more detailed description was already given in Ref. (5).

International Co-operation and Time Schedule

The HAW test disposal is performed with considerable international participation. The project is mainly funded by the German Federal Minister for Research and Technology (BMFT) and the Commission of the European Community (CEC) and is carried out in close cooperation with the Netherlands Energy Research Foundation ECN. Since 1988, the French Agence Nationale Pour la Gestion des Dechets Radioactifs (ANDRA) is participating in the field of dose and dose rate measurements and calculations, in the performance of laboratory irradiation experiments and in in-situ inclinometer measurements. Also, the Spanish Empresa Nacional de Residuos Radiactivos (ENRESA) is participating in the salt irradiation program.

The present project schedule foresees transportation and emplacement of the radioactive canisters in 1989. Taking into consideration a duration of five years, the in-situ test will be terminated in 1994. The necessary post-test investigations will need at least two years.

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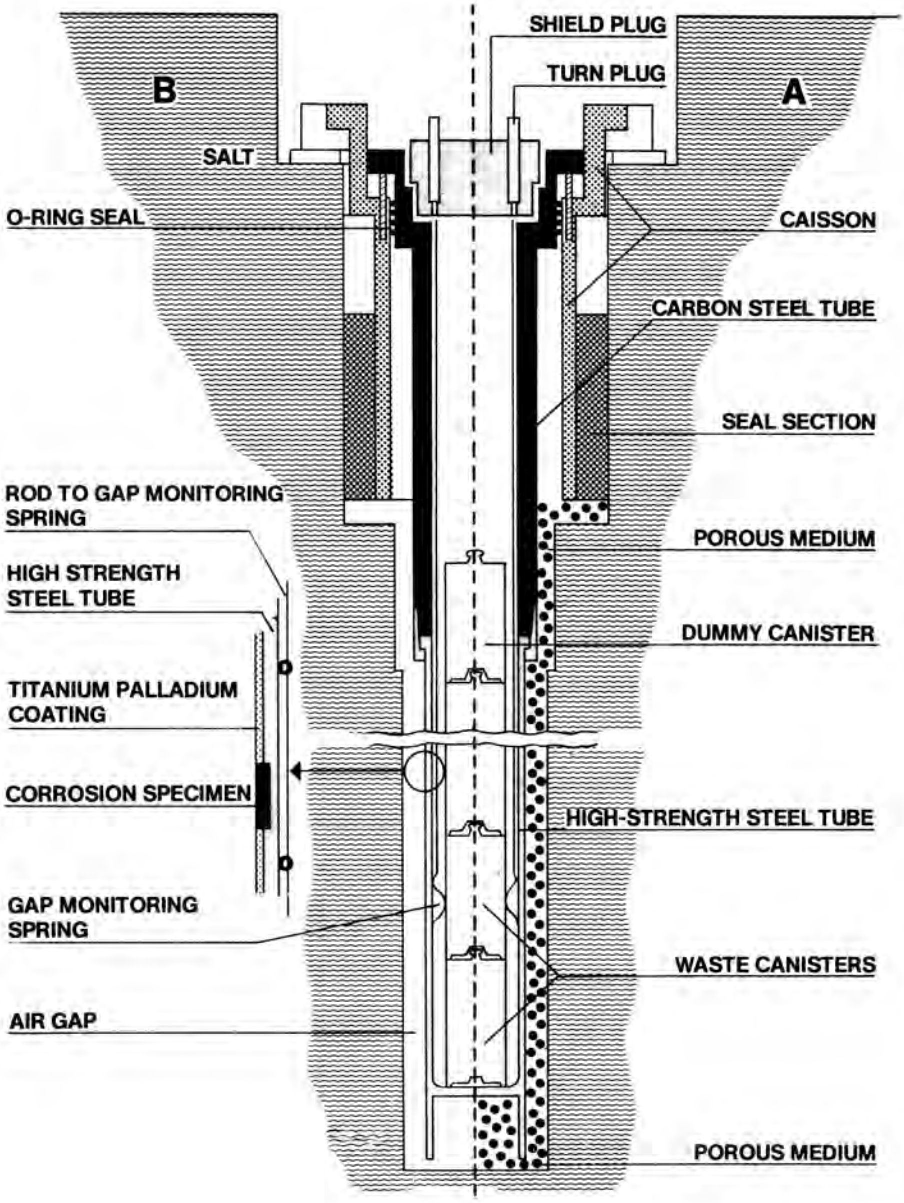

Fig. 6. Borehole Types.

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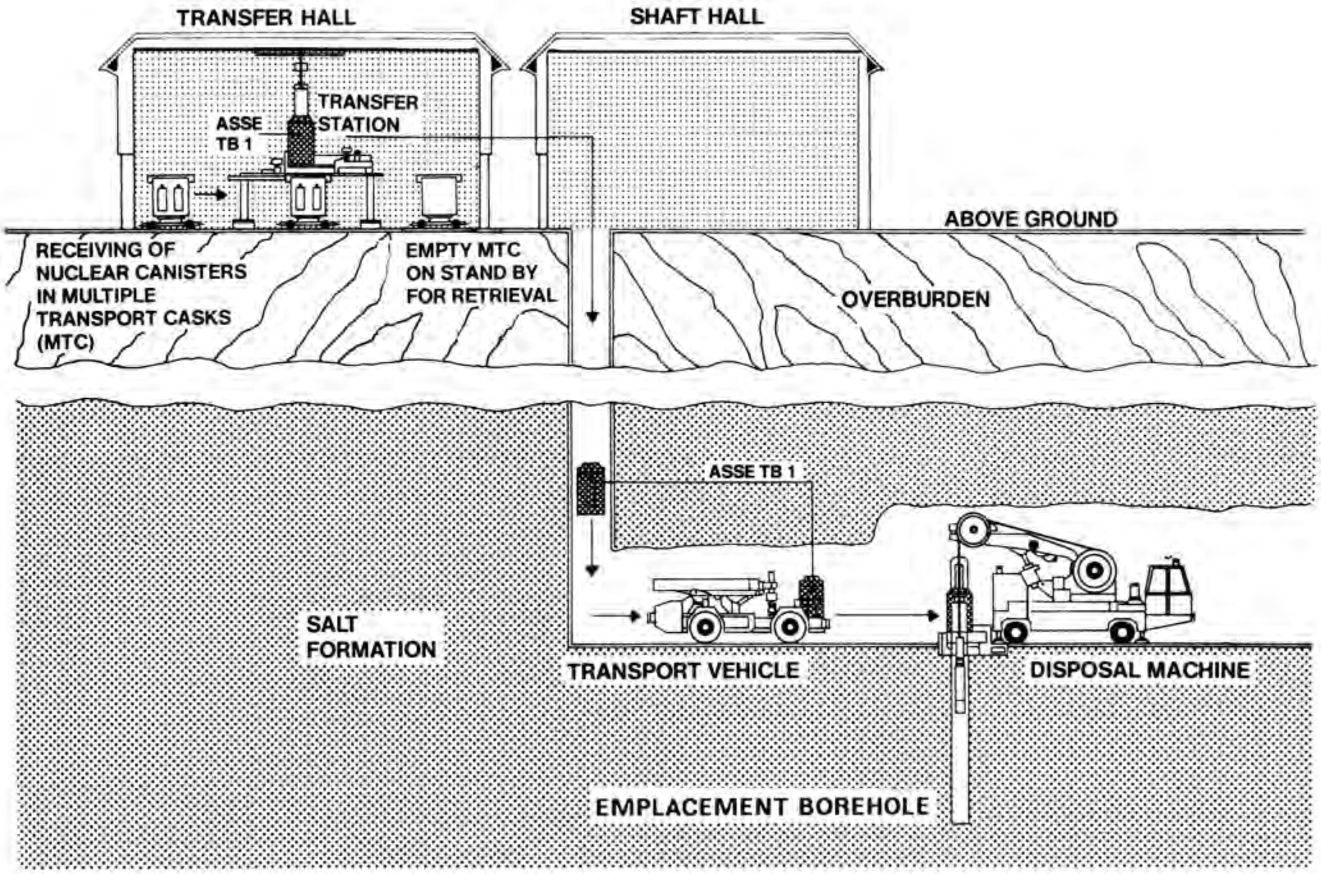

Fig. 7. HAW Handling System at Asse Salt Mine.