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Field experiments in salt formations

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Field experiments in salt formations started as early as 1965 with Project Salt Vault in the Lyons Mine, Kansas, U.S.A., and with the purchase of the Asse salt mine by the German Federal Government. Underground tests concentrated on the heat dissipation around buried high-level radioactive wastes and the geomechanical consequences of their disposal. Near-field investigations cover the properties of water and gas release, radiolysis and corrosion. Further objectives of field experiments are the development and underground testing of a handling system for high-level wastes. The performance of an underground test disposal for such wastes is not only considered to be necessary for technical and scientific reasons but also for improving public acceptance of the concept of radioactive waste disposal.

1. Introduction

Three main groups of rocks have been investigated world-wide for their potential as host rocks for the disposal of radioactive wastes: evaporites, mainly rock salt, and to a lesser degree also anhydrite; crystalline rocks, mainly massive granitic intrusions or plutons; and argillaceous sediments, mainly thick clay seams. In spite of the fact that field experiments in the three groups of rocks have nearly identical objectives, there are two main differences between rock salt and the other geological formations: (i) the interior of rock salt formations, especially in the form of massive salt domes or diapirs, does not contain any migrating groundwater; and (ii) rock salt is more easily soluble in migrating groundwater than the other rocks. These two differences directly influence the objectives and layout of the respective field experiments. Those for crystalline and argillaceous rocks have *per se* to take into account all questions that originate from the natural contact between groundwater contained in the host-rock formation and radioactive wastes disposed of therein. Field experiments in salt formations, however, are only performed for the hypothetical event of a breach in the natural barrier of rock salt and contact of groundwater with the waste containers within them.

2. Major field experiments in salt formations

Field experiments in salt formations for the disposal of long-lived and highly radioactive wastes have been done since the early 1960s, as may be illustrated by the following chronology:

1957 The National Academy of Sciences/National Research Council (NAS/NRC) of the United States published a study on radioactive waste disposal on land, proposing for the first time the use of geological formations, especially rock salt.

1963 First field experiments were performed by Oak Ridge National Laboratory (ORNL) for the U.S. Atomic Energy Commission in the Hutchinson salt mine, Kansas, to test the direct disposal of liquid high-level waste. This was, however, only a very short test, the concept of which was not pursued later on.

1964/65 The Federal Republic of Germany decided to dispose of all categories of radioactive wastes in deep geological formations, mainly in rock salt. The Government purchased the former salt mine at Asse, which was shut down for economic reasons on 31 March 1964. This mine was and is extensively used for field experiments.

1965–69 The first integrated field experiment for the disposal of high-level radioactive wastes was performed by ORNL in the Lyons salt mine, Kansas, U.S.A. This test, named Project Salt Vault (PSV), was one of the most successful field experiments, and used spent MTR-fuel elements instead of solidified high-level wastes, which were not available at that time. However, in spite of this fact its objective was not the demonstration of the disposal of spent fuel.

1967–78 About 120000 containers, 77% consisting of 200 l steel drums, with low-level radioactive wastes were successfully disposed of in the Asse salt mine.

1968 The first field experiment with electrical heaters was performed in the Asse salt mine to investigate the near-field consequences of emplaced high-level wastes (HLW).

1972–78 About 1300 drums with solid or solidified intermediate-level radioactive wastes were successfully disposed of in the Asse salt mine by using a remote handling technique.

1979–82 So-called brine migration tests were done by RE/SPEC for the Office of Nuclear Waste Isolation (ONWI) in the Avery Island salt mine, Louisiana, U.S.A. These tests looked into the mechanisms of liberation of brine inclusions through heating. Such inclusions of brine may be included in salt in very minor amounts.

1979 The Dutch energy research centre ECN drilled a 300 m deep borehole from the 750 m level in the Asse salt mine. For this experiment a dry drilling technique was used for the first time for such a borehole. After drilling, convergence or creep experiments at normal and elevated temperatures were performed in this hole.

1982 Sandia National Laboratories (SNL) drilled two shafts at the Waste Isolation Pilot Plant (WIPP), located near Carlsbad in southeast New Mexico, USA. WIPP is the first construction in the world of a specifically designed underground laboratory and later a repository for trans-uranic contaminated wastes (TRU-wastes). At present, WIPP is heavily used as an underground laboratory for the investigation of all questions related to the disposal of solidified high-level defence waste.

1983–85 The bilateral U.S.–German cooperative Brine Migration Test in the Asse salt mine is investigating the simultaneous effects of heat and radiation on salt. In addition to the tests performed in Avery Island, this field experiment uses ^{60}Co sources with a total radioactivity of about 36 kCi.

1985 After an extensive surface exploration programme of the Gorleben salt dome by the Federal Republic of Germany, sinking of two shafts has been started, to investigate the inner structure of the diapir at the level of the proposed repository.

1986–87 Three potential repository sites in the United States will be investigated by exploratory shafts as prescribed in the U.S. Waste Policy Act of December 1982. One of these sites is located in Deaf Smith County, Texas. The potential repository horizon consists of bedded salt of the Permian Salt Basin.

1987 An R&D and demonstration field experiment for high-level radioactive waste will begin in the Asse salt mine. During this experiment 30 glass blocks will be disposed of in a test to last for about 5 years. These high-level radioactive glass blocks will be especially fabricated for the experiment at the Battelle Pacific Northwest Laboratories,

Richland, Washington, U.S.A., with a total amount of 7 MCi ^{137}Cs and 3 MCi ^{90}Sr. Besides the very important objective of investigating a complete transport and handling system for solidified high-level wastes, this experiment will examine particularly the question of gas production by radiolysis.

3. Objectives of field experiments

The major objectives of field experiments in salt are:

the development and testing of disposal techniques for different types or categories of radioactive wastes;

the procurement of data and parameters for the design and construction of a repository;

the procurement of techniques and procedures for the shut-down and sealing of a repository;

the procurement of input data and parameters for computer models to predict the long-term behaviour of a repository;

the procurement of data and parameters for safety analysis or performance assessment.

To meet these objectives many field experiments have been performed, are being undertaken or are designed for the near future in those countries that are considering rock-salt formations as a suitable option for the disposal of radioactive wastes. These are mainly the United States, the Federal Republic of Germany and the Netherlands. Although Denmark does not at present have any nuclear power reactors, some site investigations and field experiments have been undertaken in the salt dome of Mors. Only little information is available on field experiments in the former salt mine of Bartensleben, located in the German Democratic Republic. This salt mine, however, is used as repository for low-level and intermediate-level radioactive wastes and is named ERAM (Endlager für radioaktive Abfälle Morsleben). Information is also scarce for field experiments in the Soviet Union although it is known that that country also focuses its efforts for radioactive waste disposal on salt formations.

3.1. *Disposal techniques*

Low-level radioactive wastes (contact handled) and intermediate-level radioactive wastes (remotely handled)

A number of *in-situ* tests have and will be performed for the development of disposal techniques. In the Asse salt mine about 120000 drums of contact-handled low-level wastes have been emplaced. This technique has been taken over by PTB for the engineering design of the Gorleben repository. The same is true for remotely handled intermediate-level waste, 1300 drums of which were disposed of in the same mine. One main objective of the WIPP-facility in New Mexico, U.S.A., is also to prove the handling and emplacement techniques for contact and remotely handled TRU-wastes.

High-level radioactive wastes (remotely handled)

A complete set of equipment for handling HLW (here simulated by MTR spent fuel) has already been used and proved during Project Salt Vault. Also at WIPP, a limited amount of HLW will be emplaced for test and investigation purposes. At Asse, a complete handling and emplacement system is currently under design, so that the previously mentioned 30 high-level glass blocks can be emplaced for a test in early 1987.

In-situ *solidification of liquid low-level and intermediate-level radioactive wastes*

An alternative disposal technique for LLW and ILW into a cavity is currently being developed and tested in the Asse salt mine in the Federal Republic of Germany.

3.2. *Design and construction*

A great number of *in-situ* investigations were performed to produce data for the design and construction of repositories. The main investigated items are: the mechanical behaviour of rock salt; dry drilling of deep boreholes with large diameters; heat dissipation in rock salt; the thermomechanical behaviour of rock salt; and the convergence of boreholes at ambient and elevated temperatures. Special attention was paid to the thermomechanical behaviour of rock salt because of the creep phenomenon.

3.3. *Shut-down and sealing*

The general issue of shut-down and sealing is common to all types of geological formations. Salt has, however, two special characteristics: first, it is soluble in water, and second, it shows viscoplastic behaviour (creep), especially at elevated temperatures. The areas of shut-down and sealing, namely backfilling of disposal rooms, closing of disposal rooms, sealing of disposal boreholes, closing of drifts, dams, and shaft seals, have to take care of these special aspects. *In-situ* investigations for shut-down and sealing are still at an early stage.

3.4. *Long-term behaviour*

Many of the following items have already been mentioned in §3.2:
Heat dissipation in rock salt; thermomechanical behaviour of rock salt, other salt rocks and overburden rocks; release of water or gases from salt rocks; radiolysis; permeability of rock salt; heat-induced fracturing of rock salt; stability against seismic events. It is especially important to predict all these near-field and far-field phenomena over a long period up to several hundreds and thousands of years.

3.5. *Performance assessment*

Besides the HLW canister performance, which is similar for all types of geological formations, the solubility of rock salt leads to some specific characteristics of this formation that require investigation *in situ*. Studies of water or brine intrusion are being done in the Federal Republic of Germany: measurements in flooded shafts; flooded drift experiment in the Asse mine; and flooded mine experiment in the Hope mine.

4. Site investigations for salt repositories

In-situ investigations in salt that have been made successfully in a number of countries around the world have led to such positive results that actual sites for the construction of repositories for several types of radioactive waste are currently under investigation, or will be in the near future. These are:

investigation of the Mors Salt Dome, Denmark, by deep drillings;

investigation of the Gorleben Salt Dome, Federal Republic of Germany, by shallow and deep drillings;

geological and hydrological characteristics established for seven salt sites in the U.S.A. (Deaf

Smith County, Texas, Permian Salt Basin; Swisher County, Texas, Permian Salt Basin; Davis Canyon, Utah, Paradox Salt Basin; Lavender Canyon, Utah, Paradox Salt Basin; Vacherie Salt Dome, Louisiana; Richton Salt Dome, Mississippi; Cypress Creek Salt Dome, Mississippi);

investigations of salt in the U.S.S.R.;

investigation of the Asse Salt Mine, Federal Republic of Germany;

investigation of the Bartensleben salt mine, German Democratic Republic, for ERAM = Endlager für radioaktive Abfälle Morsleben.

The last two were, are and will be used for the disposal of low-level and intermediate-level radioactive wastes only.

5. Conclusions

Beside theoretical calculations and laboratory investigations, field experiments are needed to verify the concept of disposal of radioactive wastes in geological formations. The main reasons are the complex nature of a large rock mass which cannot be simulated in the laboratory, and the numerous interactions of radioactive wastes with the rock mass into which they are emplaced. A large number of field experiments in salt formations that were mainly done in the United States and the Federal Republic of Germany have shown in connection with site investigations that the concept of disposing of all categories of radioactive wastes into salt formations can be realized and that its long-term safety can be proved.

Discussion

R. H. Flowers (*Authority Fuel Processing Directorate, AERE, Harwell, U.K.*). How does Dr Kühn estimate the probability and consequences of flooding of a salt cavity in the distant future?

K. Kühn. By careful investigation of the salt structure and by careful construction of the repository within the salt formation, the probability of flooding of the repository is made nearly zero during the operational phase. Before decommissioning of the repository, all its underground drifts and rooms will be completely backfilled. In addition, creep of the salt will further compact the backfill material. Consequently the probability of flooding in the distant future is even closer to zero than during the operational phase.

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