BRINE MIGRATION FIELD TEST PLANS FOR ASSE, W. GERMANY

Frederick F. Klein, Westinghouse Electric Corporation,
Advanced Energy Systems Division, Pittsburgh, Pennsylvania

ABSTRACT

The emplacement of nuclear waste in a repository in rock salt is thought to cause movement of the small amount of brine in the salt toward the waste package due to temperature and pressure gradients introduced by the waste package. This water could accelerate corrosion of the package and it is, therefore, important to understand the motion of this water and its behavior around the waste package. This paper describes a test which is to be conducted in the Asse salt mine in West Germany to verify that theories of brine migration determined in the laboratory adequately describe the conditions in a repository. The test is designed to impose a thermal and radiation field upon the salt which would be representative of proposed repository designs and to observe the amount and rate of water release from the salt. Several individual test sites are proposed to allow variation of significant test parameters and to differentiate between the different existing theories of brine migration. The paper discusses the mechanisms of brine migration, the basis for the experiment design, and the test hardware.

BACKGROUND

The extensive rock salt formations that exist throughout the world are being considered as potential sites for nuclear waste disposal. Favorable characteristics of rock salt for nuclear waste disposal include the high thermal conductivity which would reduce waste temperatures, the plastic behavior of salt under stress which will tend to close fractures or openings in the salt and restrict access of groundwater, and the fact that the soluble salt has existed for hundreds of millions of years indicates that it is in an area of restricted groundwater access.

One of the characteristics of salt which is being studied is the influence of the small amount of water in the salt on the performance of the waste package. Rock salt deposits typically contain between about one-tenth and one percent water (less than nearly all other rocks). It has been observed in previous field tests[1] and in the laboratory[2,3] that this water will move through the salt toward a waste package due to the temperature and pressure gradients developed from emplacement of the waste package. This water could exist as concentrated brine and cause accelerated corrosion of a waste package. The waste package designer can accommodate brine arrival if provided with a good estimate of the quantity and characteristics of the brine.

Laboratory testing has been and is continuing to be conducted to characterize the behavior of brine migration in salt. A field test program is being conducted to assure that laboratory derived flow rate parameters apply in the actual disposal environment. One step in this field test program is being conducted in the Asse Mine in the Federal Republic of Germany, F.R.G., (West Germany) as a part of a cooperative program between the U.S. and F.R.G. Reasons for conducting the test at Asse include the availability of a suitable salt formation with facilities for conducting testing, the ability to handle radioactive materials in this mine (which will not be available in the U.S. for several more years), and the sharing of costs and information between the partners.

BRINE MIGRATION PHENOMENON

Brine migration was first noted in the Project Salt Vault[1] testing in 1967 where it was noted that about three liters of water were released from the salt at each canister over an eighteen month heating period. Subsequent laboratory investigations[2] disclosed that very small (0.1 to 0.01 mm) inclusions of brine within salt crystals will slowly move up a thermal gradient. The mechanism for this motion, shown in Fig. 1, is dissolution of salt from the hot side of a liquid brine inclusion and diffusion of the concentrated salt solution to the cold side of the inclusion where it becomes supersaturated at the lower temperature and recrystallizes. Thus, the liquid brine moves slowly toward the source of heat. Jenks[4] has summarized the knowledge of this mechanism and developed a correlation that relates the velocity of the migration to the temperature and temperature gradient, Fig. 2. As is noted on this figure, and even more so in other studies,[5] there is considerable

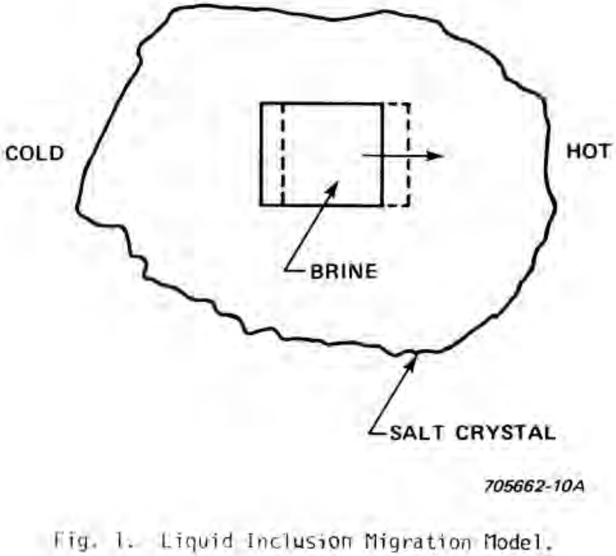

Fig. 1. Liquid Inclusion Migration Model.

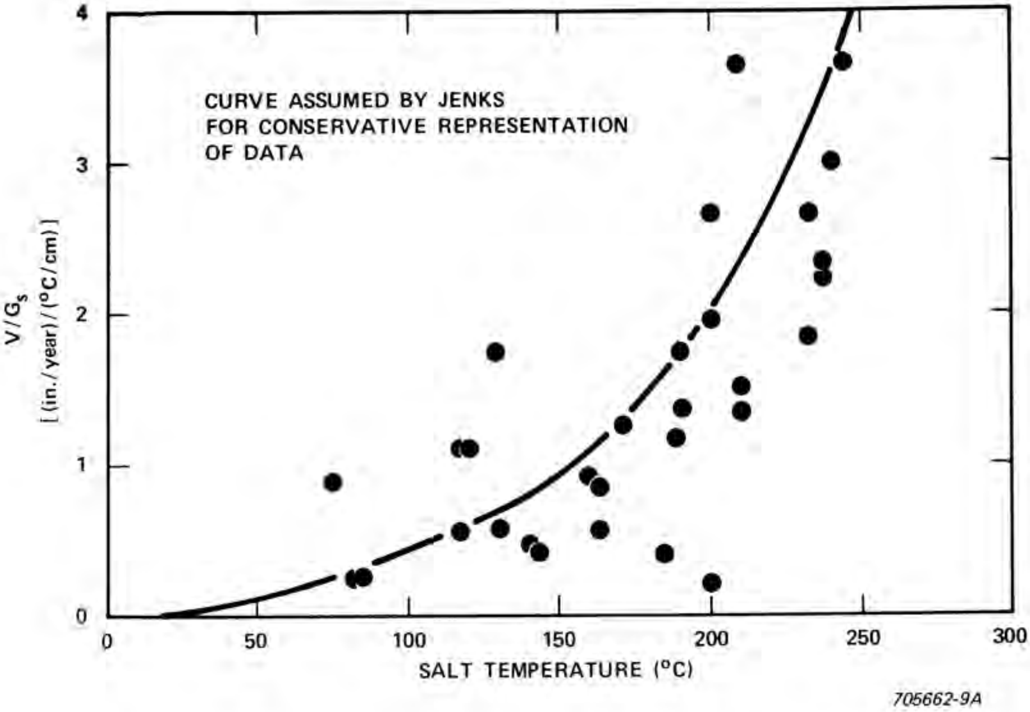

Fig. 2. Some Liquid Inclusion Motion Experimental Data and Jenks Curve Fit.

variation in observed rates of migration. Further, almost all research has been conducted within single crystals of salt; little is known about the behavior of inclusions at grain boundaries where they could be trapped or along which they could travel at faster or slower rates.

Another mechanism for the movement of water within salt which is being explored by Ron Hadley of Sandia Laboratories.[3] In this mechanism, called vapor transport, Fig. 3, brine existing in the pore spaces between salt crystals evaporates and travels through connected porosity toward a sink. Motion of water vapor can be forced by pressure differences between the saturation pressure of the brine (at elevated temperature due to waste emplacement) and a lower total pressure at the borehole, or at a slower rate due to water vapor diffusion toward the borehole due to concentration differences. Uncertainties associated with this model include whether the pressure driven flow behavior is best described as Darcy or Knudsen flow (which depends on the characteristics of the flow passages), and the magnitude of the salt permeability. The permeability of salt is extremely low and difficult to measure. It is affected by stress on the salt and probably by salt creep. Little is known about permeability of salt in situ or how the permeability changes as a result of waste emplacement. Finally, the water vapor source term is ill defined. The distribution of water among its three most common forms in salt; brine inclusions within grains, brine inclusions on grain boundaries, and as water of hydration of various minerals included in the salt; is difficult to determine. Then, the water vapor pressure of these sources as a function of temperature and the amount of water removed must be determined to define the source term for vapor transport.

As can be seen from the preceding discussion, there is currently a significant degree of uncertainty in the behavior of the water in the salt around a nuclear waste package. Although much of this uncertainty will be resolved by ongoing laboratory investigations, it is clear that relevant testing must be conducted in salt under typical repository conditions which include the effects of temperature, stress, and radiation on the salt.

BRINE MIGRATION TEST

The brine migration test equipment described here is intended to expose significant volumes of salt to

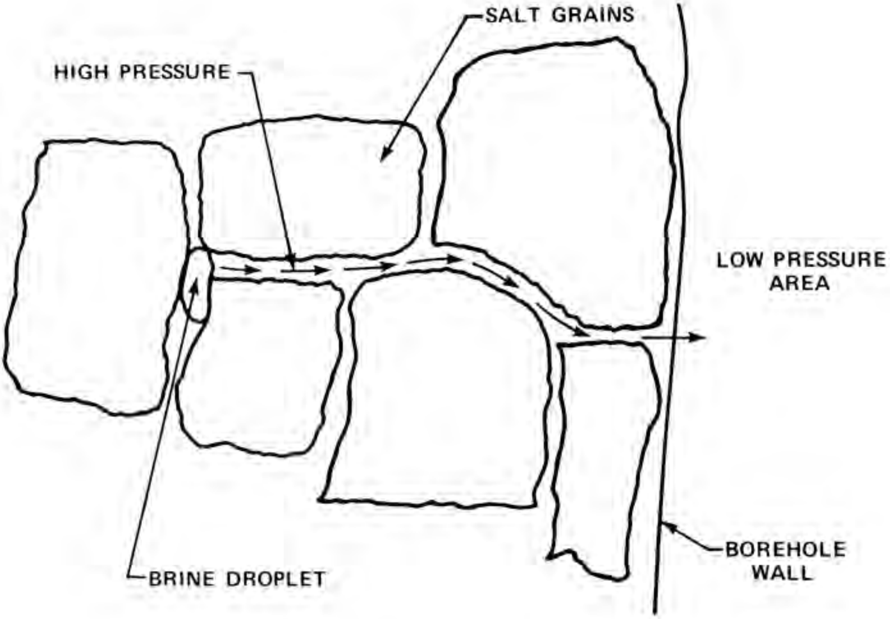

Fig. 3. Vapor Transport Model.

repository-like conditions and allow collection of water released from that salt. The salt temperature, borehole gas pressure, and gamma radiation level can be varied to allow measurement of the effects of these parameters on migration behavior. These parameters will be varied by establishing individual test sites, each having its own set of parameters.

The test equipment consists of a 5 meter long cylindrical sleeve inserted into a vertical borehole in the salt, Fig. 4. This sleeve contains a radiation source, electrical heaters, and instrumentation in the lower two meters. Just above the active length of the sleeve, an elastomeric seal isolates the annulus between the borehole wall and the heated length of the sleeve from the mine atmosphere. This annulus is used to collect water during the course of the test.

Since an unsupported borehole gap would close up by creep of the salt due to the compressive stress at the 800 meter test depth and the increased creep rate due to elevated temperature, the annulus will be filled with small beads of a nonreactive ceramic, alumina (Al_2O_3). These beads will prevent the salt from closing upon the sleeve. They will also provide a porous volume which will be used to collect water produced by the test. The water will be removed by evaporation of the water in a carrier gas which is circulated through the test volume. The carrier gas will be circulated to the mine floor where water will be collected by condensation in a cooler. The carrier gas will then be reinjected into the test volume.

The temperature around the test section will be conditioned by electric heaters in the test section and by a ring of guard heaters placed around the test assembly, Fig. 5. The purpose of the guard heaters is to simulate an elevated background temperature as in a repository, which will allow a higher salt temperature near the test section without having an excessive temperature gradient in the salt. A maximum salt temperature of 210°C and temperature gradient of 3°C/cm will be used in the test, which slightly exceed expected repository conditions in order to accelerate the test.

A high-level gamma radiation source is provided to expose the salt to a dose rate of $3X10^8$ Rads/year, which approximates the maximum dose due to commercial high-level waste (HLW) disposal. This radioactive source is provided by Cobalt 60 pins totaling about 2 meters long and 20,000 Ci per test. Cobalt 60

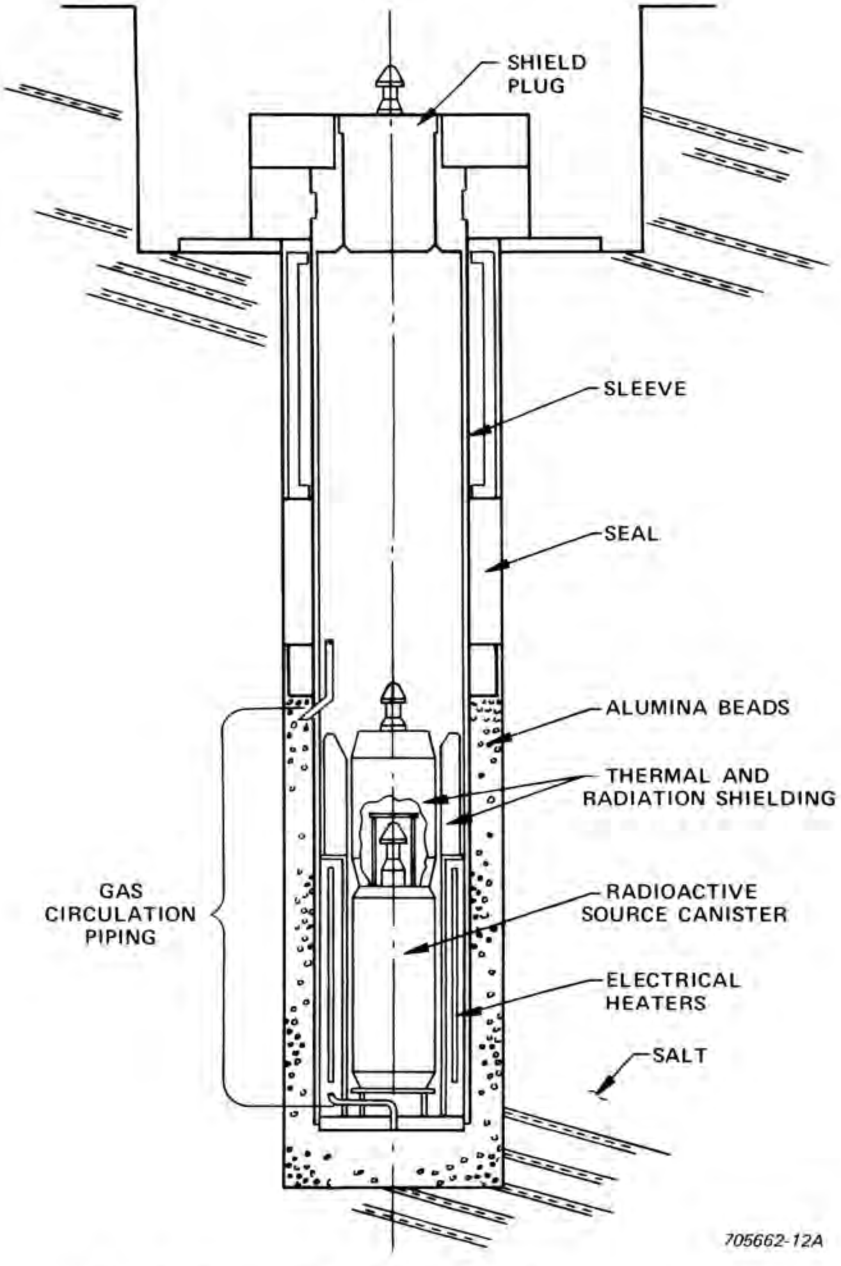

Fig. 4. Section View of Test Assembly.

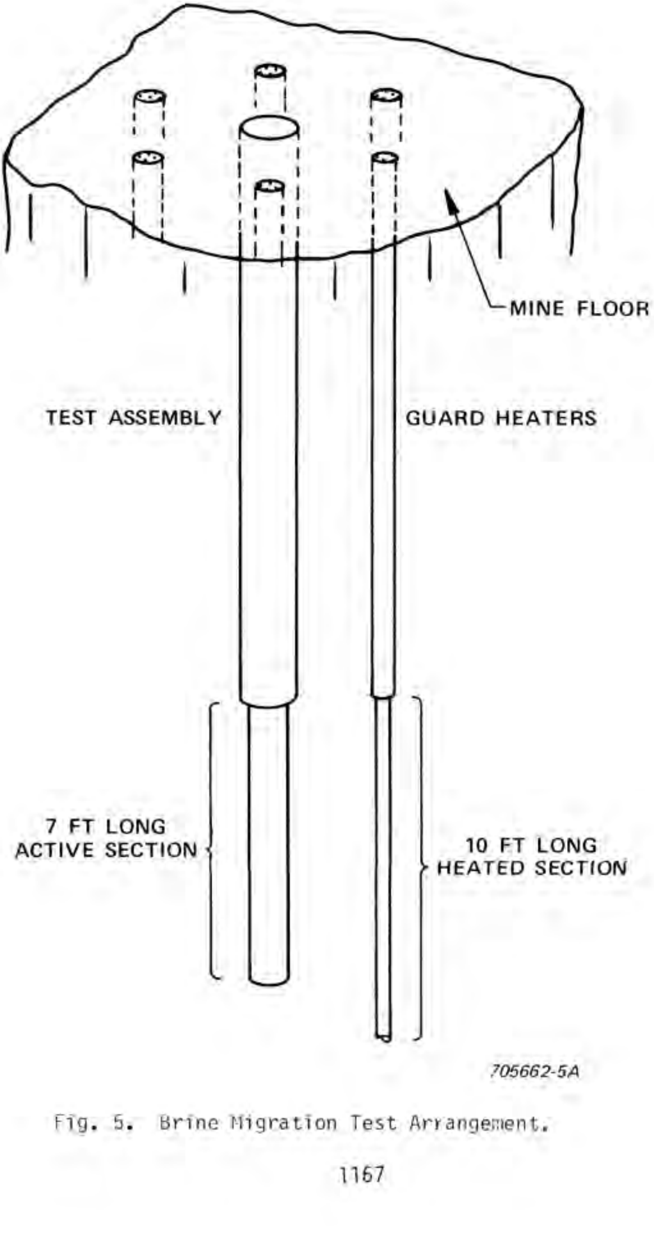

Fig. 5. Brine Migration Test Arrangement.

was selected for availability, convenience, and safety considerations. Its gamma emissions are reasonably similar to those from HLW or spent fuel. The sources will be produced in Europe and procured by F.R.G. Transportation and emplacement of the sources into the test assemblies will be provided by the F.R.G. using a transfer cask that is basically similar to others used in similar tests in the U.S., Fig. 6, although these designs have not yet been completed. The source, which is double encapsulated and loaded into a 20 cm diameter by 1 meter long canister for handling, would be loaded into the test assembly by opening the bottom door of the transfer cask, opening the door of a sliding shield placed over the test site, then lowering the canister into place. A second canister would be loaded similarly, followed by a shielding plug for the top of the assembly. With the shielding plug in place, the sliding shield can be removed for maintenance but will normally be left in place to facilitate rapid source removal in the event of a mine accident.

EXPECTED RESULTS

Thermal profiles to be generated in this test are shown in Fig. 7. It will require only about a month to approach steady state at these temperatures. The magnitude of water expected to be released by testing at Asse has been calculated using available models. The Asse salt contains about 0.05 percent water by weight and most of this water exists as hydrated minerals. These minerals will release the water of hydration at a rate that is dependent upon the local temperature and water vapor pressure. Little liquid water occurs in the Asse salt, thus, migration of liquid inclusions is expected to produce a negligible amount of water. Since it is expected that this test will be applied in the future at other test sites which would include significant quantities of liquid inclusions, the production rate of water by liquid inclusion migration was evaluated. Assuming that the water was present as liquid inclusions, about 0.4 liters of water would be produced, Fig. 8. The water density profile radially outward from the center of the heated section is shown at the end of the simulation at 2 years in Fig. 9. These calculations were performed at Westingnouse using the MIGRAIN computer program developed by Science Applications, Inc.[6]

The expected production of water by the vapor transport process has also been calculated assuming expected values of salt permeability in the range of 1.0 and 0.1 microDarcy and that the

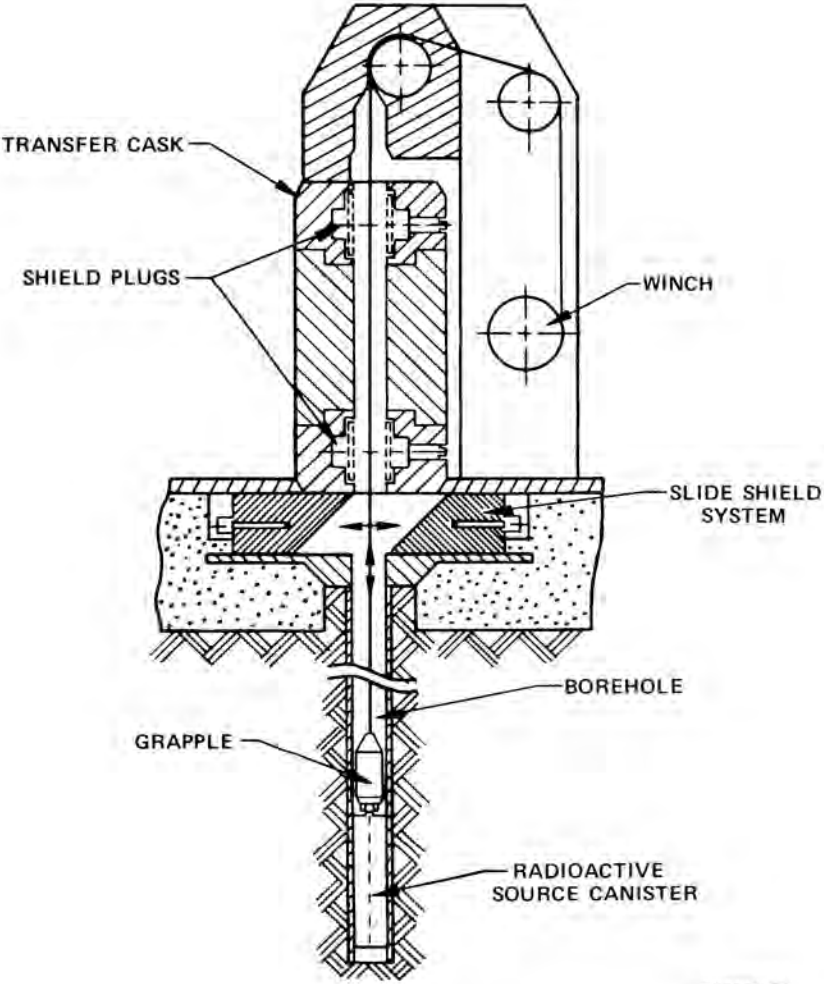

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Fig. 6. Radioactive Source Transfer Cask.

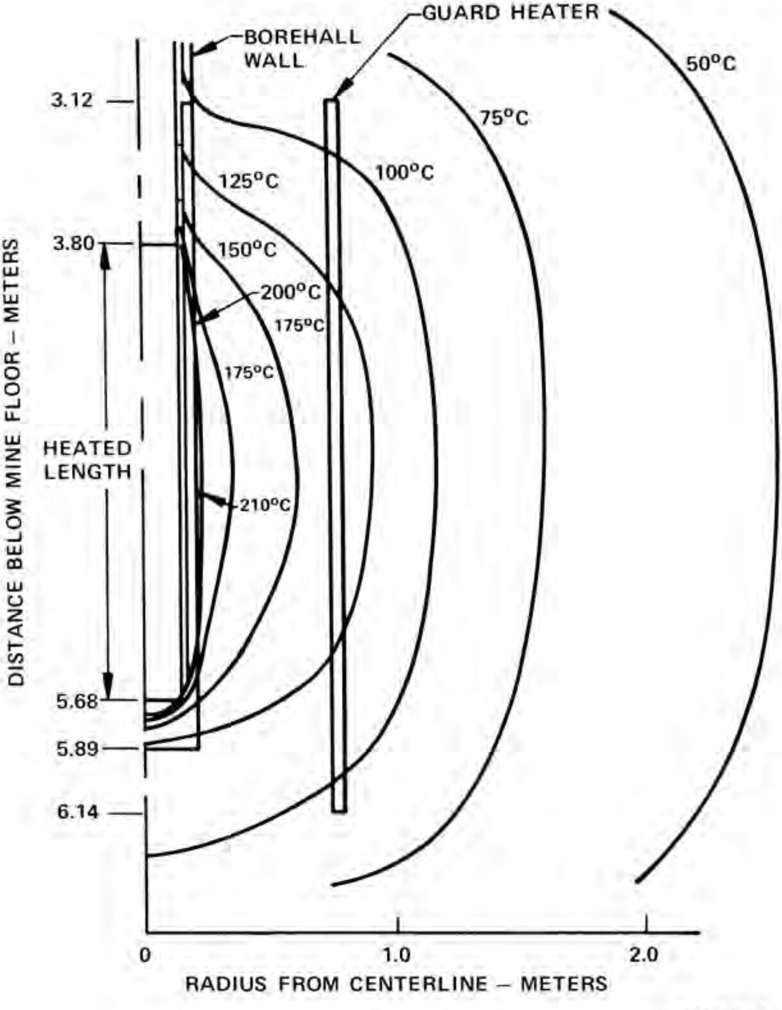

Fig. 7. Steady State Salt Temperature Isotherms.

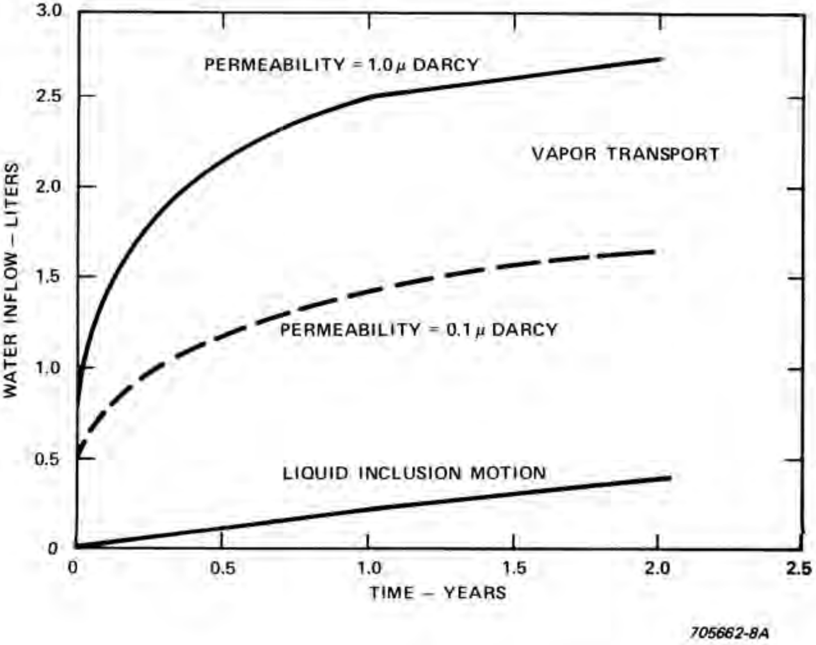

Fig. 8. Asse Brine Migration Test. Predicted Water Production Assuming 0.05 Wt-% Water.

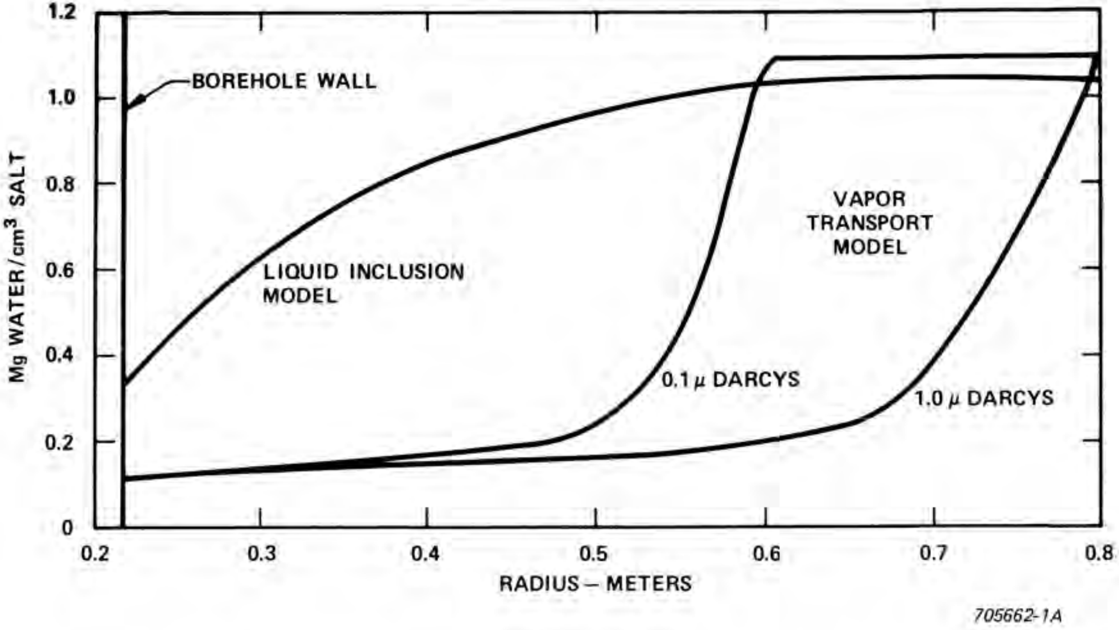

Fig. 9. Predicted Distribution of Water Content After Two Years of Operation of Brine Migration Test.

vapor pressure of the water in the salt is that of a concentrated salt solution. Fig. 8 shows the water production rate (which does not include the salt heatup period which would reduce the early production), and Fig. 9 shows the water concentration profile at the end of this time. These results show that for these assumptions, vapor transport proceeds significantly faster than does liquid inclusion motion. Also, the significantly different shapes of water production rates and final water concentration distributions should facilitate post-test determination of which of these mechanisms has a dominant influence on water motion in salt.

It is noted that this result would be obtained in a salt, other than at Asse, which includes liquid inclusions. The expected result at Asse is to observe the vapor transport migration behavior, the effects of radiation and to establish that the test equipment functions in a satisfactory manner. Other tests will be conducted at varying conditions at a site other than Asse, to determine the change in water migration characteristics with changing temperatures, temperature gradient, gas pressure and radiation level to more fully define the brine migration rates.

ACKNOWLEDGEMENTS

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