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Brine Migration Test for Asse Mine, Federal Republic of Germany: Final Test Plan

Technical Report

July 1983

Westinghouse Electric Corporation

prepared for

Office of Nuclear Waste Isolation
Battelle Memorial Institute
Columbus, OH 43201

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ABSTRACT

The United States and the Federal Republic of Germany (FRG) will conduct a brine migration test in the Asse Salt Mine in the FRG as part of the U.S./FRG Cooperative Radioactive Waste Management Agreement.

Two sets of two tests each will be conducted to study both liquid inclusion migration and vapor migration in the two salt types chosen for the experiments: (1) pure salt, for its characteristics similar to the salt that might occur in potential U.S. repositories, and (2) transitional salt, for its similarity to the salt that might occur in potential repositories in Germany.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLES

FIGURES

FIGURES (Continued)

Page

FIGURES (Continued)

PHOTOGRAPHS

1.0 INTRODUCTION

A program of testing related to nuclear waste disposal is to be conducted in the Asse salt mine in the Federal Republic of Germany (FRG) under the US/FRG Cooperative Radioactive Waste Management Agreement. One part of this program is a brine migration test which is described in this Test Plan.

In the U.S., the test program is funded by the Department of Energy through the Office of Nuclear Waste Isolation operated by Battelle Memorial Institute. Test design and contruction is by the Advanced Energy Systems Division of Westinghouse Electric Corporation and their subcontractor, D'Appolonia Consulting Engineers, under Contract No. E512-02700. In the FRG, the program is funded by the Bundesministerium für Forschung und Technologie (BMFT) at the request of the Physikalisch-Technische Bundesanstalt (PTB). The program is operated by the Institut für Tieflagerung of the Gesellschaft für Strahlen-und Umweltforschung (GSF-IfT).

The brine migration test is designed to stimulate and measure the motion of water in salt at Asse under typical repository conditions, including radiation. Observations of this motion will be useful in determining the amount of water that would be released from the salt in a repository. In addition, information about the behavior of salt and potential barrier materials will be obtained.

Two of the salt types available at Asse have been selected for testing. One is the Übergangssalz (transition salt) which is considered to be representative of repository salts in Germany and, therefore, these test results will be directly applicable to German repository design.

Testing in this salt will also provide information relative to the behavior of water in salt for the U.S. More information will be obtained by conducting tests in the Speisesalz (pure salt) which is considered to be similar to U.S. domed salt. Both types of salt, unfortunately, reportedly contain very small quantities of liquid inclusions in the salt, and so only the vapor migration theory can be observed at the Asse test site. Further testing at another location will be required to obtain information about liquid inclusion motion. The hardware developed for this test will be applicable for the future testing.

This final test plan provides a description of the objectives of the test, the basis upon which the test has been developed and a preliminary description of the test hardware and test activities and a schedule for completion and installation of the test equipment. It is noted that, although this is a final test plan, all elements of the test design have not been completed. Some of the major items yet to be determined include evaluation of the suitability of the proposed test site, the configuration of the site, the detailed design of the test hardware, development of installation, operation and post-test evaluation procedures.

One additional item should be noted. The thermomechanical analysis of the salt presented in Section 6.9 is in a very preliminary form. The results have not yet been reviewed for accuracy or suitability. They are reported here due to their potential major impact on the performance of the test and the test equipment, but these conclusions are not firm nor have corrective actions yet been taken based upon these results. This information will be finalized and more results obtained during the final design phase of this test.

2.0 SCOPE, ISSUES AND OBJECTIVES

2.1 SCOPE

Westinghouse Electric Corporation and its subcontractor, D'Appolonia Consulting Engineers Inc. have a contract with The Office of Nuclear Waste Isolation (ONWI) to design and construct hardware for a brine migration test. The hardware will be designed to stimulate and allow observation of brine migration in the field and will initially be utilized in the Asse mine in West Germany. Under the provisions of a bilateral agreement between the governments of the United States and the Federal Republic of Germany (FRG), in general terms the U.S. is to design and construct test hardware (except the shielding container for the Co-60 radiation source and the electrical power supply) and the FRG is to install and operate the test in the Asse mine.

2.2 ISSUES

Issues related to brine migration have been identified by ONWI.

2.2.1 Brine Migration

It has been observed both in the laboratory and field tests that when a heat source is placed in a salt deposit there is a tendency for the water trapped in the salt rock to move toward the source of heat. This water, occurring in different forms, can accelerate corrosion of a waste package emplaced in the salt deposit and could initiate leaching of radioactive materials from the waste form. The repository and waste package designers can design to accommodate this water, but require a reliable method to develop an upper estimate of the amount of water which could reach the waste package. Laboratory testing to determine the characteristics of brine migration can approximate the environment around a waste container in a repository, but cannot duplicate the stress field and cannot easily conduct large size, long term testing. To confirm laboratory derived models for brine migration, it is necessary to conduct field tests. These tests should be designed to measure the phenomenon of brine migration over the range of parameters which are significant to repository operation. Calculations of brine migration of liquid inclusions indicate that brine arrives at the waste package for at least one hundred years after emplacement. Therefore, a test cannot be designed to directly measure total brine influx directly. It is necessary to confirm mathematical models which can be used to calculate migration over long time periods. The value of parameters that influence brine migration such as temperature distribution, thermal gradient, borehole pressure, etc., change over time. Therefore, it is necessary to perform measurements of brine migration over a range of these parameters to confirm model input values.

There are two models of brine migration which are described in more detail in Section 6.0:

- Liquid Inclusion Migration - This is motion of small (10 - 1000 μm) inclusions of brine located within the salt crystals or on the grain boundaries. This motion is considered to be proportional to the local temperature gradient and increases in velocity at higher temperatures. It is also affected by the components of the brine, the sizes of the inclusions, the grain boundaries and the presence of other minerals in the salt, but these effects have not yet been quantized. The motion is not considered to be sensitive to borehole gas pressure or (over reasonable ranges of compressive stress) to the salt stress state.
- Vapor Migration - Water vapor, formed by evaporating water from brine in the salt porosity or from hydrated minerals, can travel via pressure gradients through the permeablity of the salt to the borehole. This model is sensitive to the water vapor pressure (which is affected by brine or hydrated mineral composition and temperature), by borehole pressure, and by salt permeability. It is not affected directly by temperature gradient or salt stress although salt stress may affect the salt permeability.

2.2.2 Radiation

The waste form emits radiation in the form of gamma rays and a low level of neutrons. This may affect the salt and brine. The salt could be affected by radiation hardening and by development of color centers and possibly by colloidal sodium. The brine, either in the salt or accumulated around the waste package, may produce gases and corrosive chemical compounds by radiolysis. Gas production in brine in the salt could form a gas bubble in a brine inclusion by expanding the inclusion volume by high pressure gas, which could reverse the inclusion's direction of motion, or possibly cause salt decrepitation releasing the water. Gas production could also increase the pressure around the waste package, perhaps enough to fracture the salt or to breach the seal between the package and the mine. The potential and effects of radiation on brine migration are not well known. No laboratory testing has been conducted while the project salt vault testing indicated little radiation impact.

2.2.3 Gas Generation

Gas can be generated by radiolysis as described above, by corrosion of the waste container or by release of gas from the salt. The effects of gas are to increase the pressure around the container and to potentially accelerate corrosion of package materials.

2.2.4 Accelerated Corrosion and Leaching

The presence of brine could increase the rate of corrosion of the waste package. The package corrosion products, along with the brine constituents, can affect the leaching of nuclides from the waste form. Therefore, simulation and observation of the environment resulting from a waste package emplacement and attendant brine migration is an important issue.

2.2.5 Altered Mechanical Properties of the Salt

The effect of heat, stress, radiation and brine on the salt around the waste package may alter the salt mechanical properties near the waste package and thus may affect the integrity of the salt containment of the waste or possibly disrupt the multibarrier waste package or interface with retrieval.

2.3 OBJECTIVES

The objectives of brine migration testing are to answer the questions raised by the above issues. However, due to the characteristics of the salt at Asse, not all of the objectives that are important to the U.S. can be satisfied by testing at Asse. Therefore, additional testing should be conducted at another site to supplement the information gained at Asse. The full set of objectives that would be satisfied by tests at a future site with other salt characteristics will be referred to as generic test design objectives, while those for the test at Asse are referred to as the Asse test design objectives.

The special characteristic of Asse salt is that it contains a very low concentration of liquid brine inclusions in the salt crystals and, therefore, it is not expected that observations of liquid inclusion migration will be possible at Asse.

2.3.1 Generic Test Design Objectives

- Confirm models of brine migration by exposing salt in the field to conditions representative of those expected to occur in a nuclear waste repository. Confirm or establish empirical rate parameters over the range of conditions important to brine migration so that the models can be extrapolated for the one hundred year or more period over which brine migration is expected to be significant.
- Observe conditions in the borehole resulting from the arrival of brine migration water including radiolysis, corrosion, gas generation, pressure and other synergistic effects.
- Observe the thermal and mechanical behavior of salt in the presence of heat, brine, and radiation and the effect of these on the salt mechanical properties.
- Qualify test methods and equipment to be used to confirm brine migration models in potential repository sites.

2.3.2 Asse Test Design Objectives

Since the salt available for testing at Asse may not be representative of salts being considered for U.S. repositories and because the relative importance of various brine migration models and the values of their relevant parameters may be sensitive to the specific characteristics of the salt, the model confirmation aspects of the Asse test are more limited. The salt at Asse is considered to be representative of the salt at the proposed Gorleben repository so the

Asse test will provide important data to confirm the brine migration characteristics at that site. The Asse test design objectives are as follows:

- Observe the migration of water in the salt available for testing at Asse. This is expected to be primarily vapor migration water movement. This salt is considered to be representative of repository sites in Germany and will also provide data applicable to one mechanism of brine migration of possible impact to U. S. repositories.

- Qualify test methods and equipment to be used to confirm brine migration models at potential repository sites.

- Observe conditions in the borehole resulting from the arrival of brine migration water including radiolysis, corrosion, gas generation, pressure and other synergistic effects.

- Observe the thermal and mechanical behavior of the salt in the presence of heat, brine, and radiation and the effect of these on the salt mechanical properties.

3.0 OVERALL TEST PROGRAM SUMMARY

The hardware for this test program is being developed to satisfy the generic test objectives and will also be used for the Asse test.

The generic test consists of several independent test sites, each having identical hardware, but operating with different input parameters. Each site consists of a central test borehole surrounded by a ring of guard heaters (Figure 3-1). The central borehole has a diameter of 43.5 cm (17 in.) and contains a sleeve 5 m (16.4 ft.) long (Figure 3-2). The lower 2 m (6.5 ft) of the sleeve, which is electrically heated and may contain a cobalt 60 radiation source, and the surrounding salt is the experiment zone. Around the heated sleeve is a 5 cm (2 in.) thick gap filled with alumina beads. A flow of gas is circulated through this gap to collect water which enters by brine migration; this water is evaporated in the gap region carried by the gas and is collected at the surface by condensing in a cold trap.

The lower sleeve protects the heaters and radiation source from brine and salt stress and is made of inconel for corrosion resistance. Since the radiation source must be retrievable, the integrity of the sleeve must be maintained. This is assured by monitoring the sleeve so that sleeve collapse or leakage is detected before the source could be trapped.

Each test site is separated from the others by at least 15 m (50 ft.) so that the temperature and strain fields do not significantly interact. The tests are differentiated from each other by varying the temperature field, the type of salt, the presence of radiation and the borehole gap gas pressure. The Asse test design will include four test sites while the generic test design would incorporate about nine test sites.

The duration of the testing will be approximately two years, but this time may be modified by the observed test results. Some tests may be terminated early

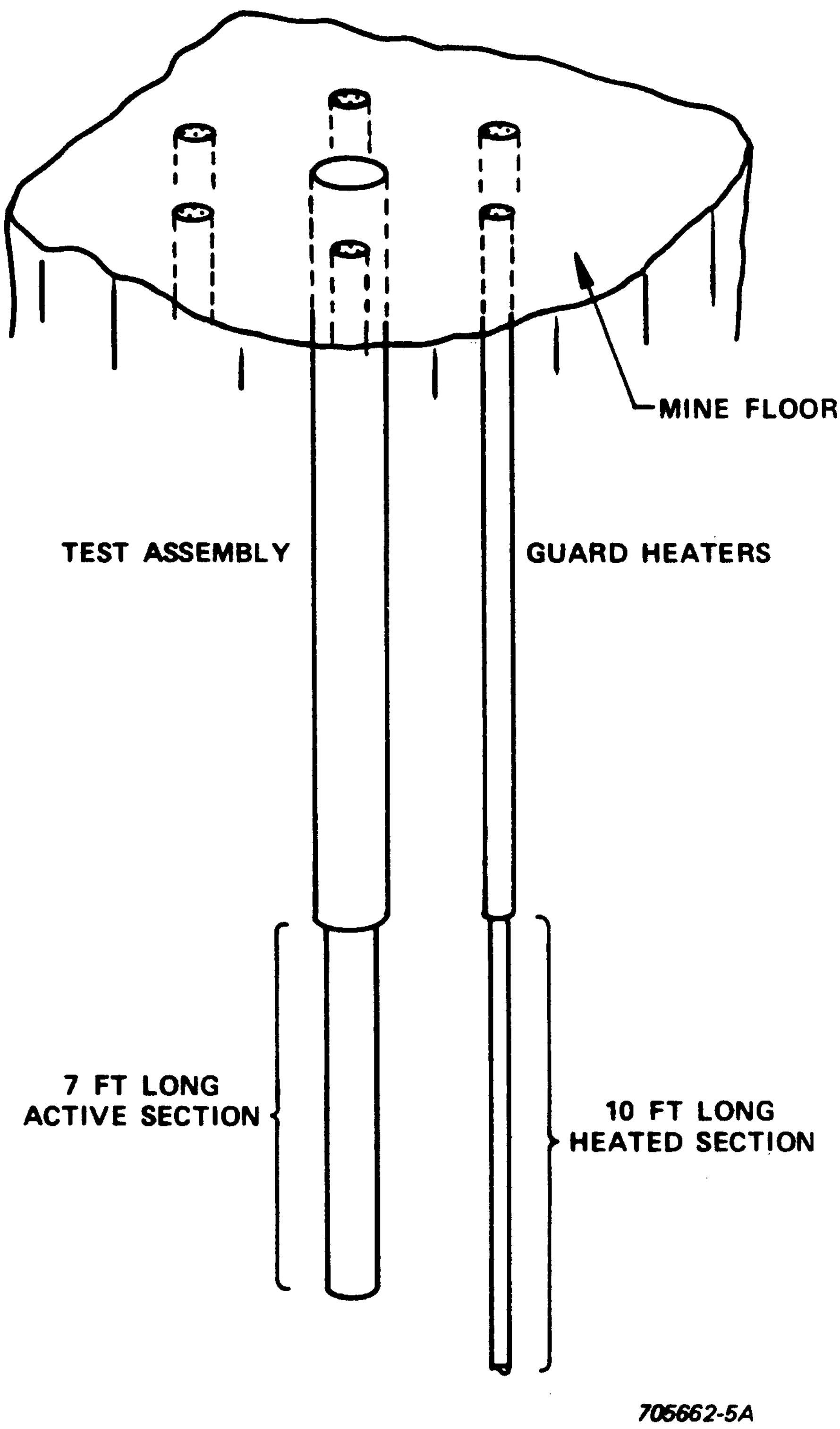

Figure 3-1. Test Site Overview

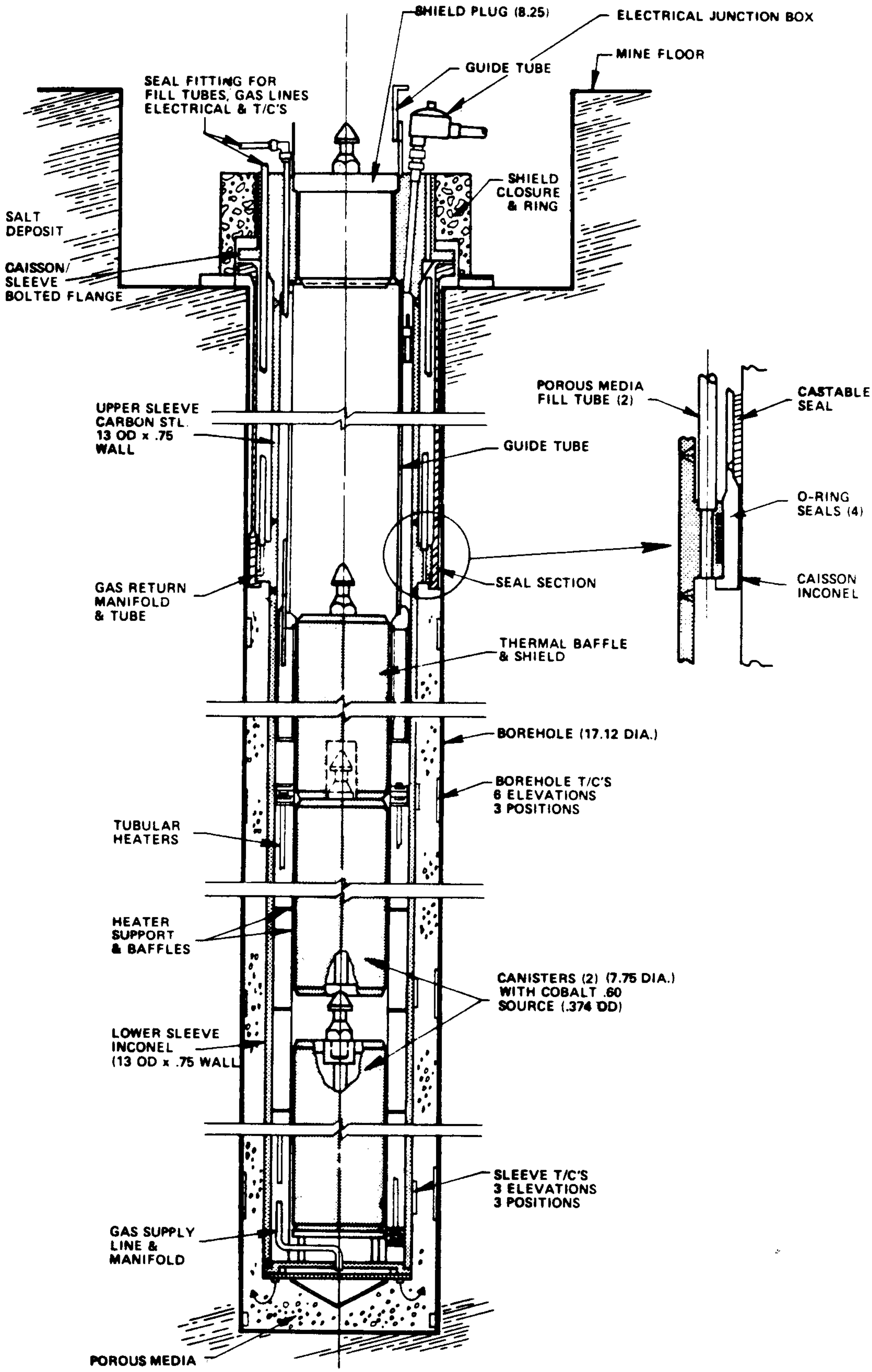

Figure 3-2. Cross Section of Brine Migration Test Assembly

and others may be extended. The times of significant support effort will be during initial installation and checkout and during test shutdown and post-test evaluation. Test operation will only require monitoring and minor maintenance, although periodic evaluation of data may result in some changes to test operation.

The primary data to be obtained from the test is the rate and total amount of water release from the salt. Models of brine migration which have been developed in the laboratory and in other tests will be used to attempt to duplicate the brine migration test results. The models must incorporate the pertinent characteristics of the salt being tested, such as water content and form, permeability, etc., in order to make meaningful predictions. Therefore, the appropriate characterization measurements must be conducted at the test site. A model which can successfully duplicate the results of the several tests in the generic test series would be qualified to be used to predict the amount of brine that would be released from an actual repository and this data may result in a less expensive design if the total water release is low. It may be necessary to repeat some brine migration testing in the actual repository material to assure that the mechanisms of brine migration are applicable to that material. The hardware and methods developed for this test should be applicable to future tests.

4.0 EXPERIMENT DESIGN BASIS

This section of the test plan describes the basis for the design of the brine migration experiment and for the selection of test parameters.

4.1 BRINE MIGRATION THEORIES

A summary description of the current theories of brine migration is presented to provide a basis for understanding the experiment design. Section 6.0 provides a more detailed description of those theories.

4.1.1 Liquid Inclusion Migration

Salt contains very small pockets of brine solutions within the salt crystals or on the grain boundaries. These are called brine inclusions. When placed in a temperature gradient, these inclusions move toward the source of heat by dissolving salt on the hot side and recrystallizing salt on the cold side of the inclusion. The velocity of the inclusion motion increases with increases in temperature gradient and with increases in temperature. The velocity is relatively insensitive to salt stress or borehole gas pressure. The effect of radiation on liquid inclusion migration is unknown, but it is speculated that radiolysis could cause formation of gas bubbles in the inclusion and these would cause the inclusion to move down the thermal gradient away from the heat source.

4.1.2 Vapor Migration

The vapor migration model describes motion of water by evaporation and flow of water vapor through connected porosity of the salt. Water in the brine in the porosity, from hydrated minerals or by liquid inclusion migration to grain boundaries is evaporated by heat from the waste package and the water vapor flows through the salt by pressure or concentration gradients to the borehole. The flow rate due to vapor transport is increased with increases of salt temperature (via increased source water vapor pressure) and with decreases in borehole total pressure or water vapor pressure, but is less sensitive to temperature gradients. The effect of salt stress may be to alter the salt permeability, but this is not well established in situ. The effect of radiation is unknown.

4.2 CONSTRAINTS ON TEST EQUIPMENT

The following experimental equipment constraints are imposed by the facilities available at Asse.

- The maximum weight of any piece of equipment is ten metric tons (22050 lbs) - determined by lift capacity.
- The maximum envelope for any piece of equipment is 1.1 m (3.6 ft) x 2.2 m (7.2 ft) x 5.0 m (16.4 ft) - determined by lift capacity.

4.3 TEST PARAMETER BASIS

The test objectives are listed in Section 2.3. This section discusses the means by which basic test parameters are selected to meet these objectives. The primary objective is to design experiments to determine the movement of water in salt in the vicinity of a waste package in a repository environment. Behavior of the water after it reaches the salt-waste package boundary is of interest but is a secondary consideration. That will be observed in post-test evaluations. In order to simulate the repository environment, the following parameters must be established.

- Waste type being simulated
- Temperature
- Temperature gradient
- Stress state
- Radiation exposure
- Borehole gas pressure
- Test geometry
- Time

4.3.1 Waste Type Being Simulated

The parameters listed above vary depending upon the type and age of waste to be disposed of, the overall design of the repository, and the design of the waste package. The first consideration is the waste type, with spent fuel or commercial high-level waste (HLW) being considered. The environment for high-level waste is more severe with respect to peak heat load and radiation dose rate than for spent fuel. The German disposal concept is to implace commercial high-level waste in long boreholes with many waste canisters stacked vertically. The maximum salt temperature is to be limited to about 200°C (Röthemeyer, 1979).

The most recent U.S. reference design for commercial high-level waste was published in the Reference Repository Conditions Interface Working Group's (RRC-IWG) report (1983). The design has a single waste canister in a borehole. For these conditions, the maximum salt temperature would be 160°C. However, these conditions were for reference and no justification was given for reducing the average areal loading to 25 W/m^2 from the 37 W/m^2 value reported in the Claiborne et al (1980) report used by the RRC-IWG. The higher areal loading resulted in a maximum salt temperature of 211°C, and this is considered (for this experiment) to provide an upper bound on the salt temperatures considered for waste disposal.

The design of the brine migration test will be based upon commercial high-level waste at an areal loading of 37 W/m^2 as reported in Claiborne et al (1980). This is compatible with the German salt temperature limits and is more severe than the U.S. designs having lower HLW areal loadings or spent fuel disposal concepts.

4.3.2 Temperature

The maximum salt temperature and temperature gradient associated with the 25 W/m^2 loading repository conditions of the RRC-IWG report (1983) are shown in Figure 4-1. The temperature increases to about 125°C within the first month, then slowly continues to rise to a peak of 155°C fifteen years after emplacement. The slower rise is due to an elevation in the overall background temperature of the repository due to the heat input from many canisters. Later, the temperature gradually decreases due to the decay of fission products. Behavior at the higher areal loading is similar with a peak temperature of 211°C at fifteen years.

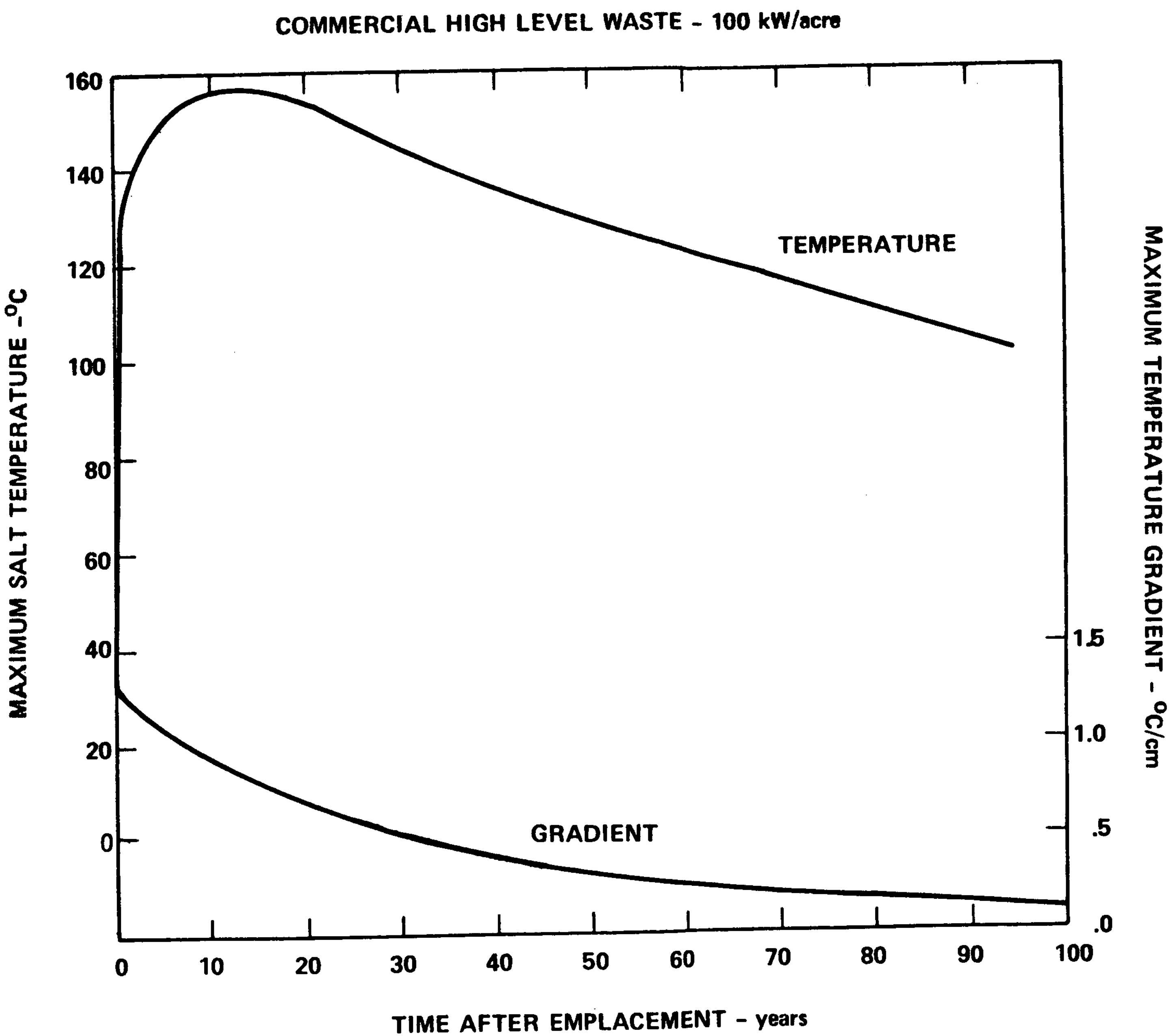

Figure 4-1. Temperature/Temperature Gradient for HLW

There is thought to be threshold behavior of the water available for motion as a function of temperature. Based on weight loss studies of Asse salt by Jockwer (1979), water is released at several distinct temperatures upon heating to various constant temperatures for 35 hours. An important phase of this release occurs from about 240 to 300°C and is believed to be due to release of water of hydration from various minerals and accounts for about two-thirds of the total weight loss. Whether this water would be released to participate in water movement in a repository at lower temperatures after much longer times is uncertain, but of significant interest. Since repository design would seek to avoid release of this large amount of water, and since predicted operation temperatures are below this release temperature, the test should operate below 240°C. It will be of interest to observe (by post-test evaluation) whether this water is released at temperatures below this threshold.

A design maximum salt temperature of 210°C is selected for this test. This gives a reasonable simulation of the maximum expected repository salt temperature. It is noted that this will be the temperature at the borehole wall and that salt further into the wall will be at lower temperatures (see Section 6.2).

A temperature of 120°C is selected as the minimum suitable for the generic test design, because below about 110°C the vapor pressure of brine is below atmospheric pressure so that the vapor transport phenomena will be less important. Also, below this temperature the amount of water produced in this test by inclusion migration will be too little to measure on a reasonable time scale. Other temperatures between the maximum and minimum would be included in the generic test series.

For the Asse test design, only a few tests are to be conducted and these will all be at the highest temperature, 210°C, in order to obtain the maximum amount of water motion. Salt at larger distances into the salt wall will be at lower temperatures so some information about a range of temperatures will be available.

4.3.3 Temperature Gradient

According to the theory of movement of brine inclusions within crystals of salt, the velocity of motion is proportional to temperature gradient above a minimum threshold which depends (at least) on inclusion size (Cline and Anthony, 1972). Traversing grain boundaries may require a high threshold gradient (Cline and Anthony, 1971). At larger gradients, large inclusions may disintegrate resulting in a collection of smaller inclusions which may move more slowly (Anthony and Cline, 1971). The vapor migration theory of water motion does not require a temperature gradient for motion, just an elevated temperature and regions with differences in vapor pressure. The maximum thermal gradient in the reference HLW repository occurs within the first year at a value of about 1.4°C/cm, then decreases with the decay of the waste products, Figure 4-1. (Other repository designs give gradients up to about 2°C/cm.) At the time of the maximum salt temperature (15 years from emplacement), the gradient has decayed to about 60 percent of the initial value. Increasing the gradient slightly above the values likely to occur under repository conditions is not believed to initiate atypical inclusion behavior, but should accelerate brine motion and thus produce more easily observed results.

The test will combine the maximum temperature condition of about 210°C with a slightly increased thermal gradient of 3°C/cm to obtain a test which is slightly accelerated, but which is not expected to initiate any unexpected phenomena. Another advantage of increasing the gradient is that this increases the volume of salt which is exposed to a substantial gradient. It is noted that the gradient decreases quickly with distance into the salt (see Section 6.2).

For the generic test design, this condition will be used as a base case and comparisons at other lower temperature and temperature gradient conditions will be made. For the Asse test, only the base case conditions will be used.

4.3.4 Radiation

The effect of radiation on brine migration is not well known. The conclusions of the Project Salt Vault (PSV) tests (Bradshaw et al, 1971; Holdoway, 1972) were that radiation does not have an important influence on brine migration since similar radioactive and nonradioactive tests produced nearly identical results.

It is unknown whether effects of radiation on brine migration predominantly result from integrated dose to the salt, integrated dose to the moving brine droplets, or dose rate to the salt or droplets. There has been discussion in Jenks (1980) that irradiation of brine inclusions might form gas (H_2) bubbles in the inclusion which may then migrate away from the heat source, but this was not observed in PSV evaluations. The effect of radiation on solid salt is to cause accumulations of colloidal sodium and chlorine in the salt which can cause formation of several gaseous products on dissolution. Also, accumulation of dislocation energy in the salt crystals could influence the migration of brine inclusions through the crystal. However, thermal and radiation annealing of the salt limits the accumulation of these effects. The dose rate to the salt seems to be the most important parameter because it affects the equilibrium level of radiation-induced reactions in the salt and brine.

The dose rate to the salt in a repository is influenced by the amount, type, and age of the waste and the waste package design. Recent studies of HLW repositories (RRC-IWG, 1983; Jenks, 1980) give values of maximum dose rate to the salt of 1.0×10^8 Rads/yr. and 3.0×10^8 Rads/yr., respectively. (The latter value is for the salt backfill case after correcting the dose rate from water to salt.) The higher value is selected for this study and also represents the maximum value that can be accommodated in the Asse mine because of weight limitations of the shielded transporter cask.

4.3.5 SALT STRESS STATE

The salt around a waste package will converge upon the package over a period of time which depends primarily upon the depth below the surface, the salt temperature, and the size of gap around the package. However, in typical configurations, the gap will close in a small fraction of the approximately 100 years which are significant to brine migration. For this test, the existence of a gap between the salt and sleeve will affect the state of stress in the salt around the sleeve by eliminating the radial stress component around the borehole, thus, potentially inducing salt cracking. Allowing the gap to close would allow a compressive stress state to develop in the salt, which would tend to close cracks in the salt and would be more representative of the repository environment. In order to allow accumulation and collection of brine and other gases, it would be desirable to maintain a gap around the test sleeve. By using an inert, porous backfill material around the sleeve, the opening can be maintained as a porous area, and the salt can be supported by the beads to maintain a compressive stress state. Ideally, the beads should be nonreactive with brine, nonabsorptive of water, not affect the pH of liquids, and be strong enough to support the lithostatic and thermal stress in the salt.

4.3.6 Borehole Gas Pressure

The borehole gap around the heated section will be isolated from the mine environment by a seal between the sleeve and the borehole wall above the heated section of the sleeve. The gap will not necessarily be pressurized. At the start of the experiment, the borehole will be flushed with dry nitrogen to remove any atmospheric water and oxygen. Following this flush, but before the heat source is applied, one of the two following conditions will be established at each test site.

4.3.6.1 Pressurized Borehole

One test condition will use a sealed borehole to allow accumulation of gases produced within the borehole and accompanying pressure increase. Retaining the gases within the borehole will have two effects. The first is that the gas pressure will be increased, potentially influencing the rate of brine migration by vapor migration. The second is that the moisture accumulated within the borehole will be able to influence the salt and other materials in the gap. However, observation of these effects during conduct of the test would be difficult. In particular, the accumulation of water in the borehole cannot be monitored easily if the water vapor pressure reaches saturation, because liquid water would condense in the gap area and this water cannot be located or quantized.

In this pressurized or sealed borehole design, the borehole's gaseous environment will be undisturbed during the test except for taking occasional small gas samples. Measurements can be taken on total pressure, temperature, and humidity during conduct of the test. At the end of the heating phase, but before the heat input is terminated, the water would be removed by the water collection system; the total gas pressure would be maintained during this collection by injecting nitrogen. The purpose of this is to measure the water collected before the experiment cooldown. Prior experiments have noted that cooldown causes salt cracking and additional water release which is not representative of repository operation. Water collection would continue during and after the cooldown phase of the test.

With a sealed borehole, gas pressure in the borehole can increase due to:

- Compression of the gas in the borehole due to borehole wall convergence
- Increase in temperature
- Release of various gases from the salt or corrosion
- Introduction of water vapor
- Formation of gases by radiolysis

Compression of gas in the borehole will be limited because the majority of the borehole volume will be maintained by the porous medium. Temperature increase will approximately double the initial gas pressure. Water vapor collected in the gap could cause pressure increase up to the saturation pressure of water at the lowest gap temperature in the gap region which is about 120°C, resulting in a saturation pressure of 0.13 MPa (20 psia). Any further pressure increase of the water vapor will be prevented by water condensation. Conversion of water to metal oxide plus hydrogen by corrosion or gas generation by radiolysis could generate large pressures (about 5 MPa, (800 psi), per liter of water reacted). If the pressure reaches the minimum principal stress in the salt (which would be on the order of lithostatic pressure, about 13 MPa (2000 psi)), the salt would hydrofracture and release the gas. To prevent this from happening, the experiment will include a pressure relief valve set at 0.4 MPa (60 psi). The relieved gas will be collected.

According to published theories, the gas pressure in the borehole will not have an influence on collection of water in the gap which arrived by the liquid inclusion migration mechanism. However, the vapor migration mechanism is sensitive to borehole gas pressure because this is a boundary condition for flow of water vapor in the salt. If the borehole gas pressure is increased to the saturation pressure of the brine in the salt or to the equilibrium water vapor pressure of the hydrated minerals, there will be no tendency for the brine to evaporate and travel through the salt to the borehole because there would be no pressure difference to cause flow (a smaller flow could occur by gaseous diffusion). If the water delivered to the borehole remains in the water vapor state, only a small amount of water vapor (about 0.25 liters liquid equivalent) can be accommodated without condensation occurring at the lowest temperature in the gap. Further inflow could continue from regions in the salt at higher temperatures, but this would be a limited volume of salt. Pressure in the gap could be reduced if the water vapor is removed by the water collection system, by leakage, or by reaction of the water with materials in the test. Even in the case of corrosion reaction, hydrogen would be released on a mole of hydrogen per mole of water basis. (In this case, some additional water motion could result from water vapor concentration driven diffusion, but at a slower rate.) Thus, for a sealed borehole, the amount of water in the borehole in this test would be expected to be reduced due to the gas pressure buildup. Additional information about the amount and state of water in the borehole will be obtained during moisture collection at the end of the experiment by observing the pressure change versus the amount of water collected.

An alternative design for the pressurized borehole tests is being considered. There is concern that the inconel sleeve, the seal, or the porous material in the gap could absorb or react with as much as 0.5 to two liters of water which is the amount expected to be produced by this experiment. The amount of water reacted could be determined by post-test evaluation, but this would not allow distinction between water produced during test operation and that released by salt cracking during experiment cooldown. Testing is being performed to determine the amount of water which might be expected to react with these materials under test conditions (Section 5.6). In particular, the reaction with water vapor is of interest because most of the material is in contact with water vapor but not with liquid water or brine. By continuously removing the water from the gap, this problem would be eliminated. The borehole gap pressure would be artificially maintained by injecting nitrogen to approximately 0.3 MPa (45 psi). This would eliminate the opportunity to obtain some of the desired data on test materials interaction with brine, but would fulfill the more important objective of measuring the water release due to brine migration.

4.3.6.2 Atmospheric Pressure Borehole

The other condition that will be maintained at some test sites will be to continually operate the moisture collection system and to relieve excess gas pressure to maintain atmospheric pressure in the borehole. The moisture collection system will maintain the water vapor partial pressure at a very low value. The gas in the borehole will then consist of the initial nitrogen fill, any other gases released by the salt and possibly hydrogen gas from corrosion of the test hardware by the water vapor in the gas. The pressure of this gas will increase, mainly by thermal expansion and by compression of the borehole area, but this pressure increase will be relieved at slightly above atmospheric pressure. The relieved gas will be volumetrically measured and collected for evaluation.

One reason for conducting a test with this condition is to obtain a continuous measure of the amount of water released from the salt. The combination of increased temperature and low water vapor partial pressure will cause nearly all of the water that enters the borehole to be removed by the moisture collection system, even recognizing the large saturation vapor pressure reauction associated with concentrated bitterns.

The reduced pressure will cause a greater production of of water if brine transport is predominantly by pressure induced vapor migration. This is due to the lower sink pressure which will cause the flow to proceed more quickly, or more flow to occur over the duration of the test. Also, with a reduced pressure, more of the water in the salt can be evaporated because a lower temperature would be required to reach saturation pressure. If the dominant mode of water motion in the salt is by liquid inclusion motion, the gas pressure in the borehole is expected to have a relatively small influence on the rate of motion.

4.3.7 Test Duration

Brine migration in an HLW repository is expected to have collected the majority of brine inflow at the borehole over 50 years and decreasing amounts for another hundred years (RRC-IWG, 1983). This test is limited to a short time compared to this duration. Therefore, the test duration should be determined based upon the time required to establish the basic conditions for the test and upon the magnitude of the expected effects. Calculations reported in Section 6.2 indicate that about six months will be required to fully establish the temperature field around the test. During and following this period, brine migration will continue with the volume of the salt from which brine is collected continuously expanding. It is important that the source of brine be beyond the disturbed zone around the borehole, which is estimated to be about five cm (2 in) thick. The amount of water collected increases with the test duration and larger amounts of water improve the measurement accuracy. Also, a longer test allows a better measure of the changing rates of water production which can be related to the mechanism of water transport. Estimates put the time required to satisfy these conditions at about two years total test duration.* This seems to be a reasonable time span for the Asse test and is compatible with the initial schedule and with the need date for brine migration information. The test design, as currently envisioned, is not tied to the test duration. Thus, the duration of the test can be decided as the test progresses, particularly if

*Estimates of vapor migration rates indicate that considerably less time would be required for the test, Section 6.

unexpected effects are observed. Some test sites can be terminated earlier while others could continue. In particular, for the sealed tests from which information cannot be obtained during the test, it might be beneficial to terminate duplicate test sites at different times to obtain rate information.

4.4 TEST SITE PARAMETERS

The brine migration test will consist of a collection of individual test sites, each of which has similar hardware, but having different operating parameters.

4.4.1 Generic Test Design Parameters

The generic test design will be composed of a number of individual test sites, each consisting of a heat source, associated instrumentation, and in some cases, a radiation source. Each test site will be independent of the others and have basically identical geometry, but will have varied parameters to attain the test objectives. The parameters to be varied are discussed in Section 4.3, and include:

Parameter	Range
Radiation	0 or $3X10^8$ Rads/yr
Pressurized Sealed Borehole	Yes or No
Temperature Gradient	0 to 3°C/cm
Temperature	120 to 210°C

These characteristics can be arranged in a matrix, Table 4-1, with selected values of the parameters. To run all combinations would be impractical, therefore, several specific combinations are selected as described below. The selected combinations are denoted by entering an identifying number in the corresponding box in Table 4-1. This is a matrix of parameters which is selected based upon current knowledge of brine migration and does not include any information about a specific test site. It is designed to answer the questions that are currently outstanding. At a later date, a different selection of parameters may be more appropriate, but would still utilize the same test hardware and methods.

TABLE 4-1. MATRIX OF TEST PARAMETERS FOR GENERIC TEST DESIGN

Radiation	Yes								No							
Gas Pressure	Yes				No				Yes				No			
T_X(1) - °C/cm	0	1	2	3	0	1	2	3	0	1	2	3	0	1	2	3
T(2) 120°C								5(3)								
170							6									
210				1,9	8	7		3				2				4

(1) Temperature gradient

(2) Temperature level

(3) Test site number

Repository Simulation Site

The first case, site Number 1*, is designed to include parameters that are closely related to the most severe expected repository values and incorporates the radiation source in a sealed, pressurized borehole with the maximum temperature and temperature gradient. This most nearly matches the conditions expected in the worst anticipated repository design case, combining the maximum repository temperature and an increased temperature gradient, as discussed in Section 4.3.3.

Pressurization of Simulation Site

A major disadvantage of site Number 1 is that the water accumulation cannot be continuously monitored because the sealed borehole atmosphere should not be disturbed. Thus, information on the rate of moisture accumulation cannot be obtained. Two approaches are taken to overcome this difficulty. The first is to run a parallel test, Number 3, with an atmospheric pressure borehole and from which moisture arrival will be continuously monitored. The particular advantage of continuous monitoring is that threshold behavior of brine migration may be observed by changes in the rate of moisture collection. In addition, the influence of borehole pressure can be observed in this test.

However, test Number 3 having an unpressurized borehole, is somewhat different from test Number 1 which has a pressurized borehole. Since there may be effects of the increased pressure on the brine migration rate (as discussed in Section 4.3.6), since it is important to know if the rate of migration varies with time, and since site Number 1 is the reference repository simulation case, it is considered necessary to run an identical test to Number 1, but reducing the test duration by half. This test site would be site Number 9. Both sites Number 3 and 9 would contain a radiation source.

Radiation Effects Comparisons

A second major comparison is to study the effect of radiation. Since Number 1 is the reference simulation case, a similar case, Number 2, would be run without radiation to evaluate the effect of radiation on the brine migration.

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*Refers to test site numbers, Table 4-1

Simultaneously, a no radiation case without borehole pressurization to allow continuous collection, Number 4, should be conducted as a direct no radiation comparison with Number 3. Numbers 1 through 4 are then comparisons at the maximum temperature and gradient conditions, with and without radiation and with and without borehole sealing.

Temperature Level and Temperature Gradient Parametric Studies

It is also desired to conduct tests to determine the effects of temperature level and gradient conditions. It is necessary to decide which of the radiation and pressurization conditions would be used to conduct this parametric survey. It is considered important to include of radiation exposure in this survey to be representative of the repository environment. In particular, if radiation is found to strongly affect brine migration, conducting these tests without radiation would not provide meaningful results. The impact on brine migration of retaining pressure in the borehole by sealing is an open question as discussed in Section 4.3.6. The additional information which would be gathered by allowing continuous moisture collection is judged to outweigh the possible benefits of having a pressurized borehole in this survey. Thus, it is recommended that this parametric survey be conducted with radiation but with continuous moisture collection.

Starting from the base case for this survey, Number 3, the temperature level, temperature gradient parametric survey includes test Number 5, which retains the maximum gradient but reduces the peak salt temperature to the minimum value considered, 120°C. Next, two cases at the maximum temperature, 210°C, but at reduced temperature gradients are considered. The first, Number 7, uses a gradient of 1°C/cm which is somewhat above the anticipated threshold gradient for liquid inclusion migration, but close enough that potential threshold effects may be observed over the test duration as the area of moisture collection spreads to radii with lower thermal gradients. An additional case, Number 8, is recommended at a zero gradient to separate the possible effects of vapor transport which are not thermal gradient dependent. One possible additional case, Number 6, is presented to include intermediate values of temperature, 170°C, and gradient, 2°C/cm.

Additional Concerns

These nine tests form the basis for the generic test design. At the time of this test, some questions may have been resolved, such as the effect of radiation. Other questions may arise, such as the effect of different salt types or backfill materials. This test equipment design will allow all of these questions to be addressed, perhaps with adjustment of some of the parameters in Table 4-1.

4.4.2 Asse Test Design Parameters

The Asse test design is more limited in scope than that described above. This is appropriate due to the currently limited knowledge of brine migration, the untried test equipment, and the desire to restrict the amount of radioactive source material introduced into the mine.

Four test sites will be used, all to operate at a maximum salt temperature of 210°C and with a 3°C/cm thermal gradient. These sites are similar to sites numbers 1 through 4 described above with an additional parameter of salt type considered. Two of the sites will be located in the transition salt which is representative of the salt expected at the FRG proposed Gorleben high-level waste repository site. The other two test sites will be located in a nearby formation of pure salt which may more nearly represent U. S. domal salt. Within each salt type, one test will be operated with a radioactive source and one without; all other parameters being the same within a salt type. The transition salt sites will operate in the sealed, self-pressurized mode, while the pure salt sites will operate in the unpressurized, continuous collection mode. These tests are summarized in Table 4-2.

The data collected from the tests at Asse are expected to help resolve several points.

- Does the presence of radiation effect brine migration?
- Does borehole gas pressure influence brine migration?

TABLE 4-2. MATRIX OF TEST PARAMETERS FOR ASSE TEST

	SITE 1	SITE 2	SITE 3	SITE 4
Salt Type	Transition	Transition	Pure	Pure
Radioactive	Yes	No	Yes	No
Pressurized Hole	Yes	Yes	No	No

All sites at 210°C maximum borehole wall temperature and 3°C/cm maximum temperature gradient.

- What is the rate and amount of water production under repository-like conditions in two types of salt?

- Observe the environment around the test equipment and changes resulting from heating, irradiation, and brine migration.

4.5 MEASUREMENT REQUIREMENTS - GENERAL

4.5.1 Water Collection

The primary interest of the brine migration testing is in the amount of water* which is released to the borehole as a function of time. Collection of this water has been performed in previous experiments by passing a gas through the borehole and trapping the water in a collection device outside the borehole. Both open and closed cycles have been used. In the open cycle (Krause, 1983; Hohlfelder, 1979), a supply of dry gas, usually nitrogen dried by a desiccant canister, is passed through the borehole at a controlled rate, the moisture is collected, and the gas is exhausted. This system has the disadvantage that any additional gases produced in the experiment are diluted and carried away. Also, the exhausted gas can carry away small amounts of untrapped moisture which is not measured. A more advantageous system has a closed cycle where the gas existing in the borehole (initially nitrogen) is used as the carrier gas (Rothfuchs and Durr, 1980). This gas is pumped through the borehole, through the collection apparatus, and returned to the borehole. With this system, the gases produced or evolved within the borehole are retained and are more easily monitored. Also, no water is lost from the system in an exhaust stream so the dew point at the outlet of the collection apparatus need not be kept at an extremely low value.

Two types of collection apparatus have been used. The first is dessicant canisters which absorb water into chemicals. These can produce very low dew points at the output, -50°C typically. Other advantages are that they are

*Water motion by inclusion migration travels as a brine or bittern while water traveling by vapor transport travels as pure water vapor. When brine reaches the borehole, the water may vaporize and condense elsewhere. In any case, only water which is vaporized will be collected. Some water may remain in the borehole as concentrated solution or hydrated minerals of low vapor pressure. These will be measured as part of post-test evaluation.

readily available and the water absorbed can be determined by weighing on a periodic basis. Disadvantages are that the output dew point cannot be controlled, they may become saturated (which cannot be observed except by periodic weighing or by adding other equipment) and that the capacity required for collection of liters of water is awkwardly large.

The other type of apparatus is collection by condensation at a reduced temperature. This sytem is used in the Asse mine and consists of calibrated glass containers in a modified refrigerator. This system has the advantages of having a controlled output dew point (by control of the temperature) and potentially large capacity.

A closed cycle system will be used which recycles the gas back into the borehole after water collection. Further, the cold trap method of collecting water be used because of the availability of control of the vapor pressure. The system will probably be implemented with a single, centrally located refrigerator to accommodate all four test sites.

An advantage of collecting the water continuously is that a measure of the rate of arrival of the brine can be obtained. However, it must be noted that not all of the water will necessarily be removed because some very low vapor pressure solutions and hydrated products can be formed in the borehole. These will be collected as a part of the post-test evaluation.

The moisture collection system includes sensors for monitoring several parameters. For diagnostic reasons as well as experiment safeguard the borehole pressure will be monitored at each test site. Other sensors include low flow alarm switches on each loop, level switches on the water collection containers, and pressure at each pump outlet.

4.5.2 Temperature

Temperature and temperature gradient are the two parameters that most strongly affect the brine migration. Experience in the U.S. at Avery Island with measuring temperatures using thermocouples sheathed by Inconel 600 has been very satisfactory, and Cline and Anthony (1972) recommended that this continue. The temperature of the salt borehole wall will be measured at several elevations and aximuthal positions to measure the temperature distribution of the salt adjacent to the gap. Additional thermocouples will be placed in the salt at the radius of the guard heaters (but between guard heaters) to measure the temperature field produced around the experiment, on the guard heaters and on the test assembly sleeve.

Thermocouples will not be placed in the salt between the guard heater ring and the borehole wall because the holes in the salt may unduely influence brine migration, particularly by vapor migration by providing a low pressure sink or by increasing fracturing in the salt. It is considered that the ability to calculate temperature distributions in salt is sufficiently well established that the salt temperature can be correctly described given a known heat input, a temperature profile on the central borehole wall, and temperature measurements at the guard heater radius.

4.6 TEST SITE GEOLOGIC REQUIREMENTS

To obtain the greatest amount of information from the proposed tests, it is necessary to carefully select the various test sites. From past experience, it is apparent that the presence of certain geological features can result in ambiguous or questionable brine migration data. For example, too little releasable moisture in the salt will make data evaluation difficult. Likewise, the presence of zones or horizons in the salt (such as clay or anhydrite) which introduce water from outside the test area or which contain water in other forms are undesirable and can obscure test results.

On the other hand, the selection of a test site cannot be so restrictive that the results are only of scientific interest with little practical application to "real" repository sites. Based on trade-offs between sites which are scientifically acceptable and realistically representative of potential salt repositories, the following site requirements have been developed to serve as a guideline for the selection and confirmation of a test area in the Asse mine.

These requirements should be viewed as objectives to be searched for, since the site will be in a natural geologic formation, and particular values cannot be specified.

4.6.1 Salt Type

With regard to the applicability of the test to U.S. conditions, it is important to select areas with the greatest percentage of primary halite in the rock (preferably at least 98 percent). Halite grain size should be less than one cm in order to obtain a suitable grain boundary density, because of the important brine migration effects associated with grain boundaries.

Other chlorides and sulfates should be at a minimum. Carnallite is undesirable since it contains water of hydration which is released below 110°C. Anhydrite seams and clay seams should be avoided as much as possible.

On the other hand, FRG potential repository sites contain greater amounts of anhydrite, polyhalite and kieserite. Therefore, two of the tests are planned to be conducted within the Übergangssalz (Transition Salt). These sites will also provide useful information to the U.S. on the importance of variations in salt characteristics to brine migration.

4.6.2 Moisture

The salt moisture content available for release during heating up to 400°C should be between a 0.05 to 0.15 percent weight loss. Greater water concentrations are believed to be due to large local content ratios of hydrated minerals that are not representative of overall conditions. A specific value for an acceptable level of spatial variation cannot be given since it depends upon the natural variations in the salt. However the objective is to minimize the inhomogeneity because extremes in moisture content make test evaluation difficult. Moisture content and form will be determined both before and after testing.

Air humidity should not affect the test itself because the test zone will be separated from the mine environment and the moisture collection system is closed. In spite of that, low and constant humidity is desired for other reasons (instrumentation, electronics, etc.) Both humidity and temperature are expected to remain fairly constant throughout the tests. The effect of air humidity during drilling of the test boreholes will be to absorb some water on the borehole walls. The effect of this will be minimized by drying the borehole with dry nitrogen prior to experiment heating initiation.

4.6.3 High Pressure Gas Inclusions

The selected sites must be free of the possible presence of high pressure gas inclusions ("popping salt") which could endanger both the success of the test and the personnel installing and operating the test. The "popping salt" conditions could cause sudden decrepitation ("blowouts" and explosions) of large quantities of salt as is known from Werra salt mines in GDR and from mines in Poland; all are located in bedded salt different from that at the Asse mine. The experience is that Asse does not contain popping salt.

4.6.4 Spatial Distribution

The required properties should be present in uniform conditions along the entire length of the gallery test section so they can be verified by logging, sampling and core drilling of the gallery walls and floor, in particular, to the effective depth of the test zone; i.e., seven meters.

4.7 TEST SITE GEOMETRIC REQUIREMENTS

The selected site must accommodate the test layout and geologic requirements, a contingency area, and potential volume for possible future test expansion.

4.7.1 Available Geometry and Volume

An area in the southeast part of the mine at the 800 meter level shown in Figure 4-2 has been identified by GSF-IfT as being available for the tests and having desired geologic conditions. This test area is located more than 60 meters to the southeast beyond the safety pillars (diameter of 50 m each) of Shafts 2 and 4. The area is about 60 m long, 30 to 40 m wide, and approximately parallel to the geologic structure. The nearest existing drift, the cross-cut leading to Blind Shaft 4, is more than 20 m to the west.

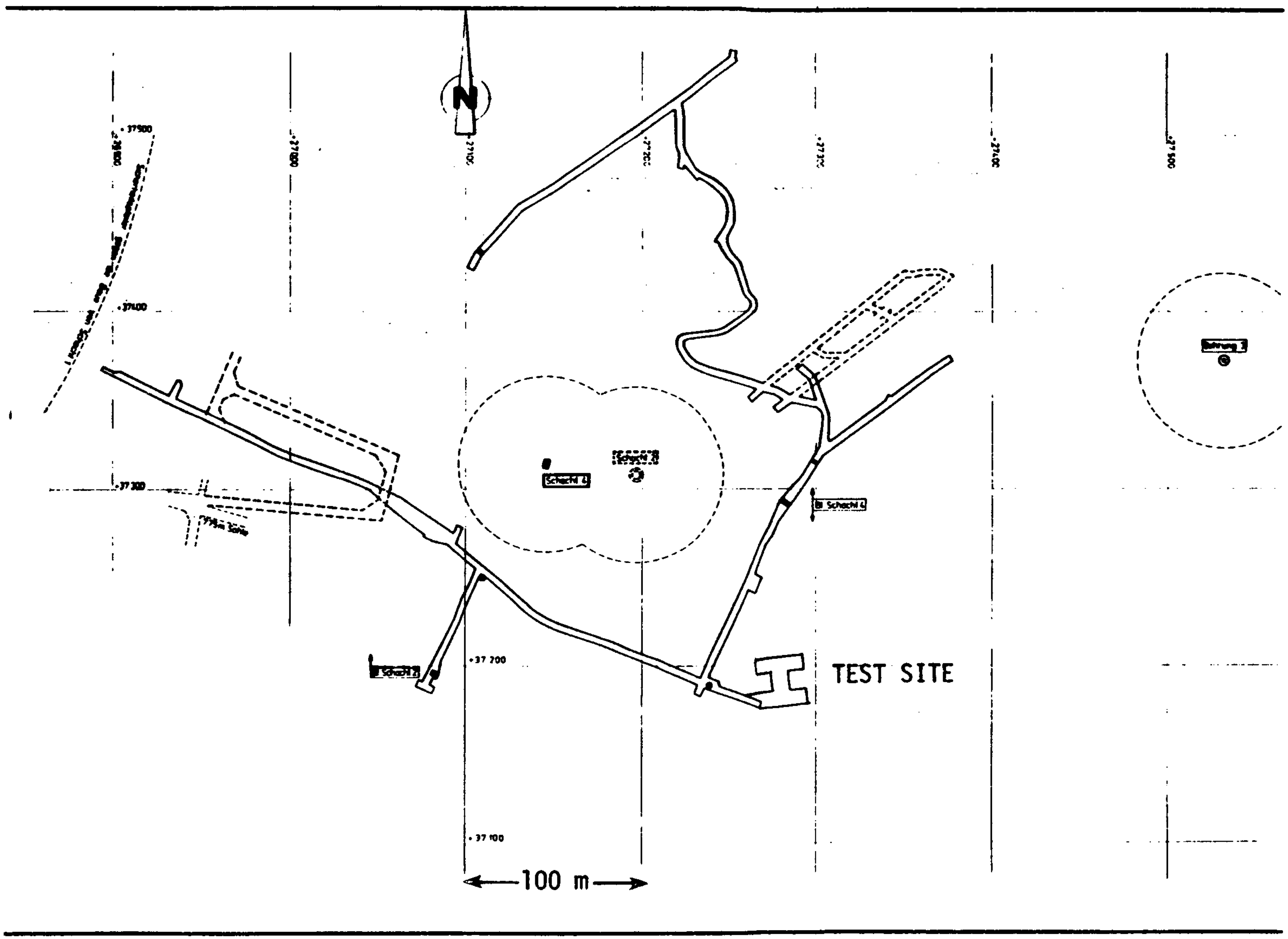

Figure 4-2. Test Plan Location in Mine

Both salt types are present in the proposed area. Pure Salt (S) occupies the southern portion at a width of 4 to 7 m in a nearly vertical formation and Transition Salt (Ü) is adjacent to the north at width of 15 to 30 m and forms a local anticline.

Extensive mining (rooms of approximate size 40 x 20 x 15 m) at the 775 m level was located horizontally more than about 20 to 40 m to the north. Reportedly these rooms were backfilled several decades ago and no further mining activities are planned for the near future. At the 750 m level, a room (No. 5) with a central pillar was excavated directly above the proposed area. This room is about 65% backfilled and full backfill is not expected before 1984. A small gallery (cross section 3 x 4 m) was excavated to the south from Room No. 5 to Room No. 7 on the 750 m level in January and February 1981. All rooms at the southern flank at 700 and 725 m levels will be backfilled in the future. However, the backfilling schedule has not yet been determined.

4.7.2 Configuration/Geometry of Excavation

The configuration and geometry of the test is derived from successful experience of previous tests, test constraints, and desired parameters from which the following are the most significant:

- Stable size of the gallery limits the width to 10 meters (33 ft) and height to 8 meters (26 ft) based on Asse mining experience.
- Avoidance of thermal interference between tests requires their location at a minimum separation of 15 meters (center to center). Strain interaction may require greater separation of parallel galleries.
- Orientation of the geologic structure at the Asse test site approximately east-west dictates similar orientation of the drift(s) for the tests to increase the probability of finding similar conditions for the corresponding tests.
- The desire to place test locations in both salt types "S" and "Ü" (Section 8) will apparently require excavation of two galleries, one in each salt type, connected by a common communication gallery.

- Symmetrical location of the test with regard to the pillars (since asymmetry creates geomechanical problems) and requirement for access from both sides dictate that the tests be located along the center line of the gallery.

- Development of an irregular stress field in the vicinity of pillar corners could impose highly asymmetrical loading on the test hardware; hence:

  - Number of pillar corners should be minimized

  - Tests should be located as far away from the pillar corners as practical, a minimum of about five meters.

In addition, the availability of substitute test locations in case of nonconformance of the selected sites with the geologic requirements and also for potential additional test locations should be considered. For example, each gallery could include the potential for extension of an additional 15 to 30 meters of length.

4.7.3 Alternate Geometries at the Asse Mine

The excavation geometry requirements discussed in previous sections could be accommodated either by a U-or Z-shaped gallery with two arms of about 25 meters long, or by an H-shaped gallery system with four arms of about 15 meters each, as indicated on Figure 4-3.

The advantage of the U- and Z-shapes is the minimization of pillar corners while the advantage of the H-shape is easier access to the test sites including alternative and/or additional sites. The Z-shape will have less rock mechanics interference between the two arms. If an additional communication link between the test galleries in the U-shaped configuration is desired, a small gallery (about 2 meters wide and about 3 meters high) or a horizontal boring could be used. A Z-shaped gallery, similar to that shown in Figure 4-3 is recommended.

4.8 TEST SITE GEOMETRY BASIS

The geometry of the test site is dictated by the successful experience of previous tests, test constraints, and the desired parameters of the test.

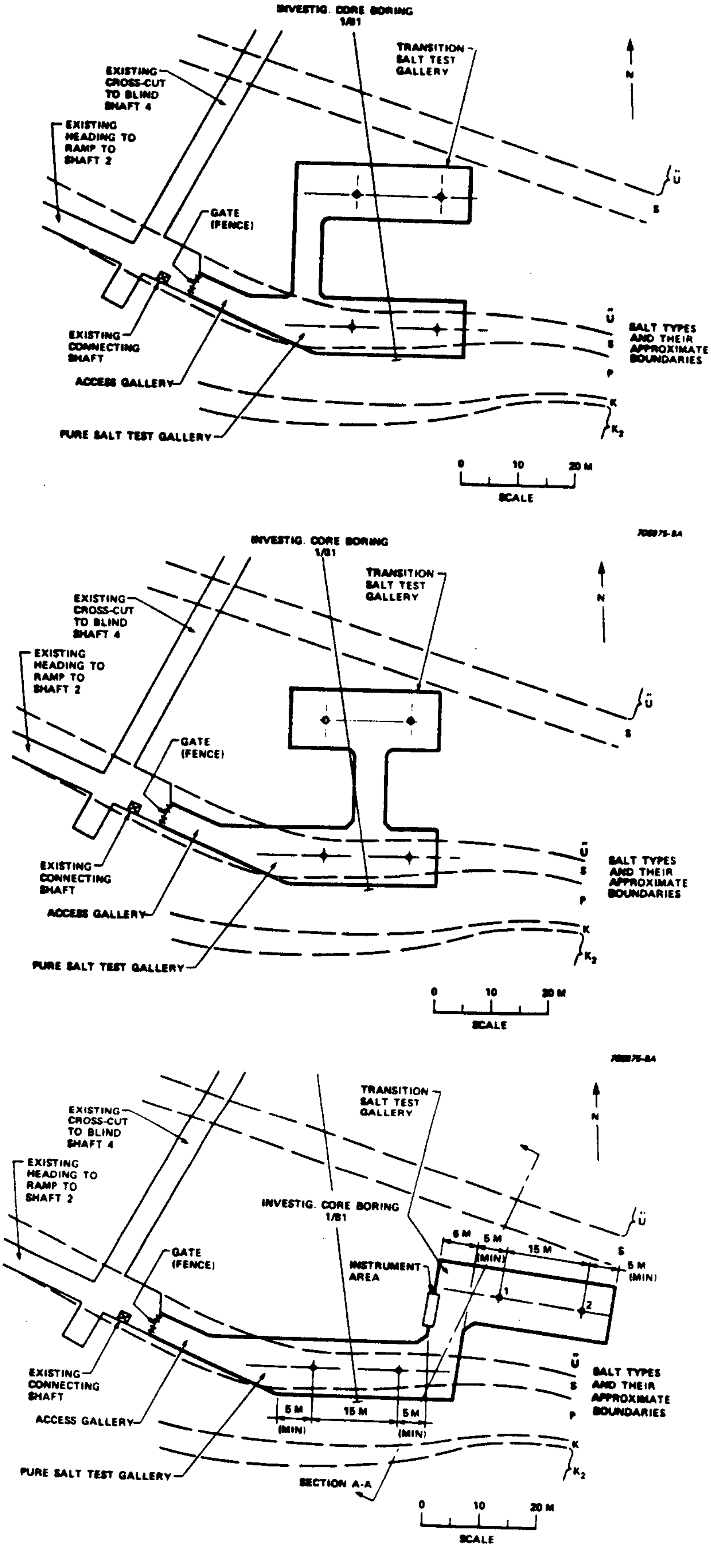

Figure 4-3. Alternate Test Gallery Geometries

Although several alternates have been considered, it has been established that independent cylindrical sources are best suited to the test objectives.

To avoid the zone of subfloor cracking that was described by the FRG, the experiments will be located a minimum of three meters below the surface of the mine floor and will be sealed at that level using cast in place epoxy seals. The heat and radiation source will be located below the seal. Preliminary hardware evaluations (Section 5.2) establish that the diameter of the test section borehole should be at least 33 cm to include the features desired. However, the experiment is constrained by use of a 20 cm diameter grapple for the radioactive source that is available for use by the FRG. To contain the other required equipment results in a borehole diameter of 43.5 cm (17 in) which will be used for this test. To obtain a reasonably long region of uniform temperature distribution around the source requires a length-to-diameter ratio of about 5 (see Section 6.2.1) which results in about a two-meter long test length. This appears to be a reasonable length from practicality considerations and would include two one-meter long radiation sources which can be accommodated by the handling equipment planned for use in the Asse test.

The test section will be surrounded by a layer of porous material such as alumina beads to allow collection of water and gases which may be produced during the test.

A ring of electrical guard heaters will surround the test. These will help to provide the desired temperature environment around the source. These heaters will be placed in a ring with a radius of 1.5 meters (60 in). Eight guard heaters will be required to obtain a sufficiently uniform temperature distribution around each site. This number is determined in Section 6.2.3.

5.0 ASSE MINE AND EXPERIMENT DESCRIPTION

5.1 MINE AND TEST SITE LAYOUT

Asse mine workings and geology are schematically shown in cross-section in Figures 5-1 and 5-2 and in plan views of the 750, 775 and 800 meter levels in Figures 5-3, 5-4 and 5-5. The test will be conducted on the 800 meter level.

5.1.1 Existing Conditions

The access to the test area is via an elevator in Shaft No. 2 to the 750-meter level and then to the 800-meter level via a series of ramps at a maximum grade of 8 percent. Then, at the 800-meter level via a northwest-southeast heading.

A number of large rooms (40 to 120 meters long, up to 25 meters wide, and about 10 to 15 meters high) were excavated at the 750-meter and 775-meter levels in the vicinity of the preselected test area.

At the 800-meter level, a northeast-southwest cross-cut is located to the west of the preselected area at a minimum distance of about 20 meters. Safety pillars of a 50-meter radius around Shafts Nos. 2 and 4 are at the minimum distance of more than 60 meters from potential test sites.

5.1.2 Description of the Experiment Geometry and Layout

Careful consideration has been given during experiment design to provide a suite of tests which can function independently of each other for reliability and together as a set with varying parameters to evaluate brine migration and other impacts. In order to keep the experiments valid, it is important to eliminate or minimize mutual interaction between the various tests. In addition, it is necessary to place comparable experiments in areas with nearly identical rock properties. The Asse test design will include a total of four tests in two rock types (Pure Salt, S, and Transition Salt, Ü), two in each rock type.

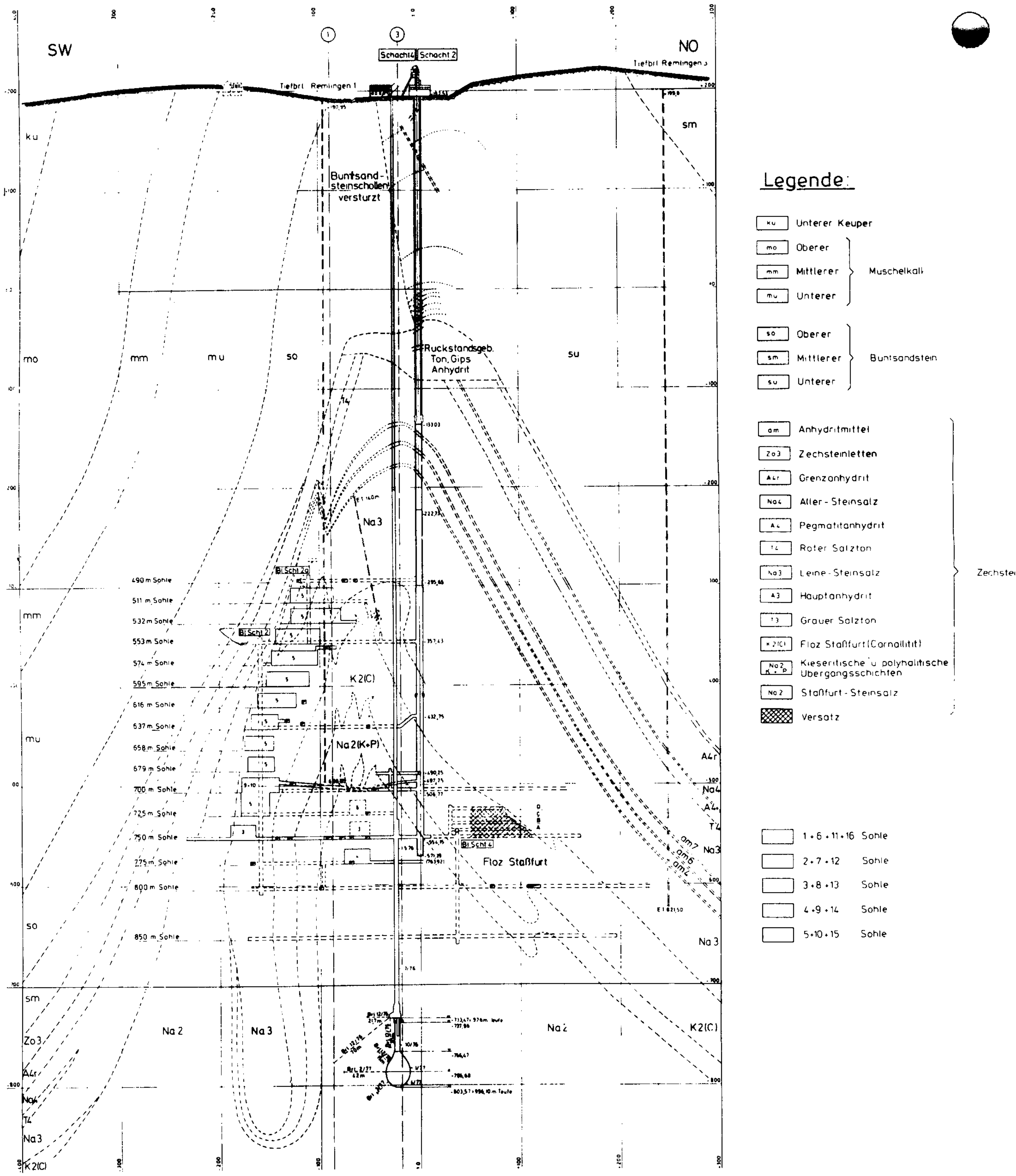

Figure 5-1. Asse II Mine Cross Section

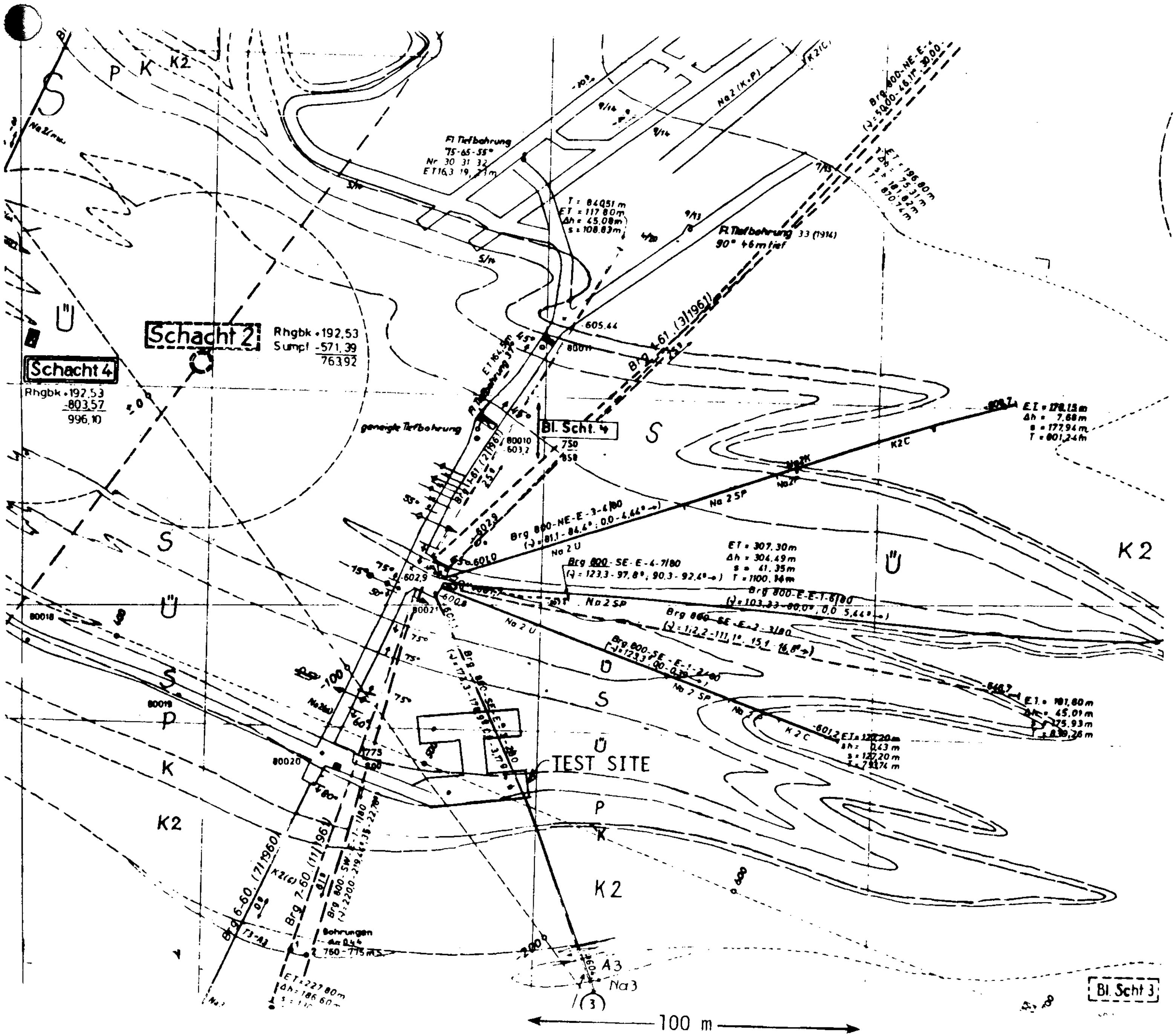

Figure 5-2. Cross Section Mine Geology 800 Meter Level

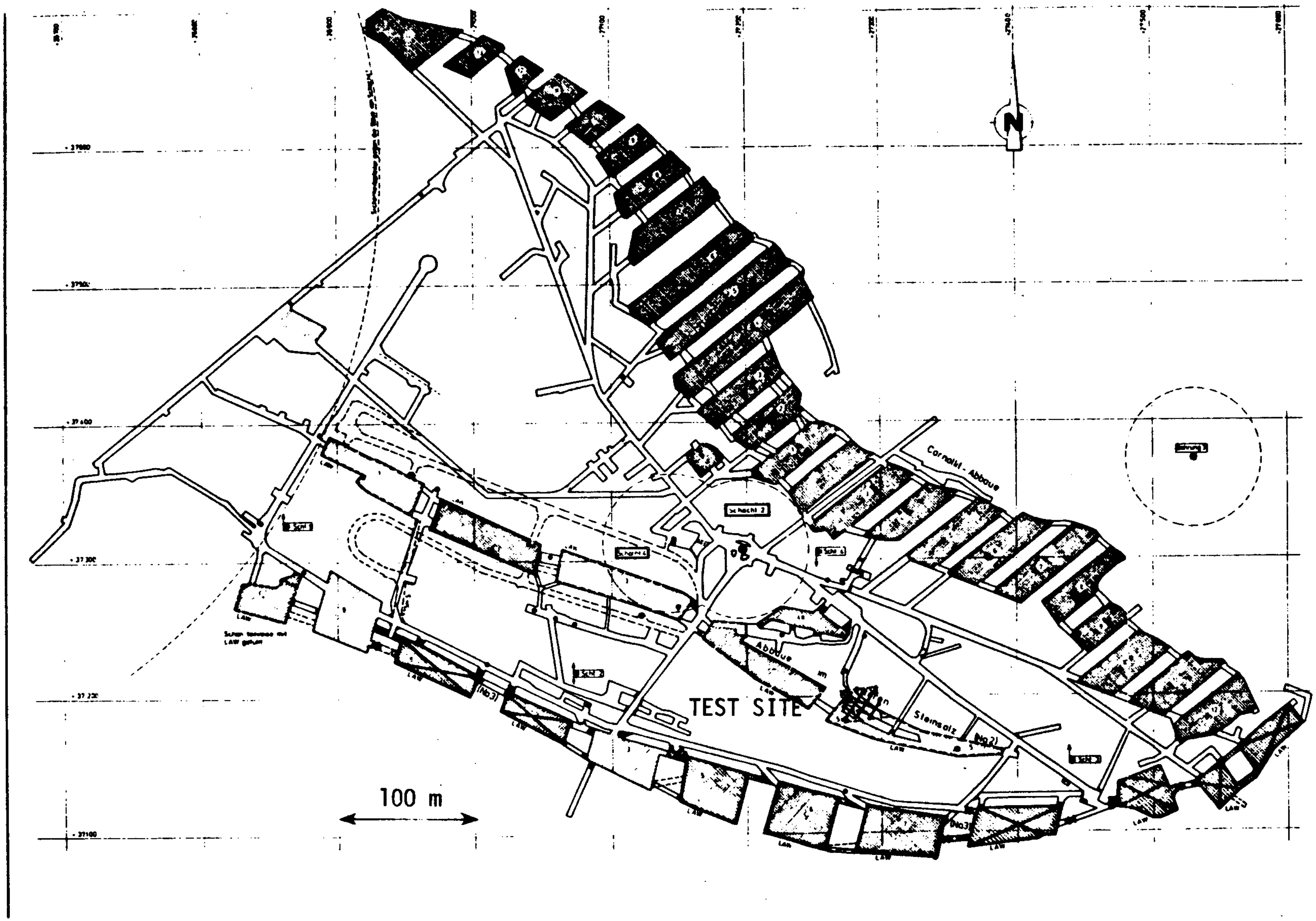

Figure 5-3. Mine Plan - 750 Meter Level

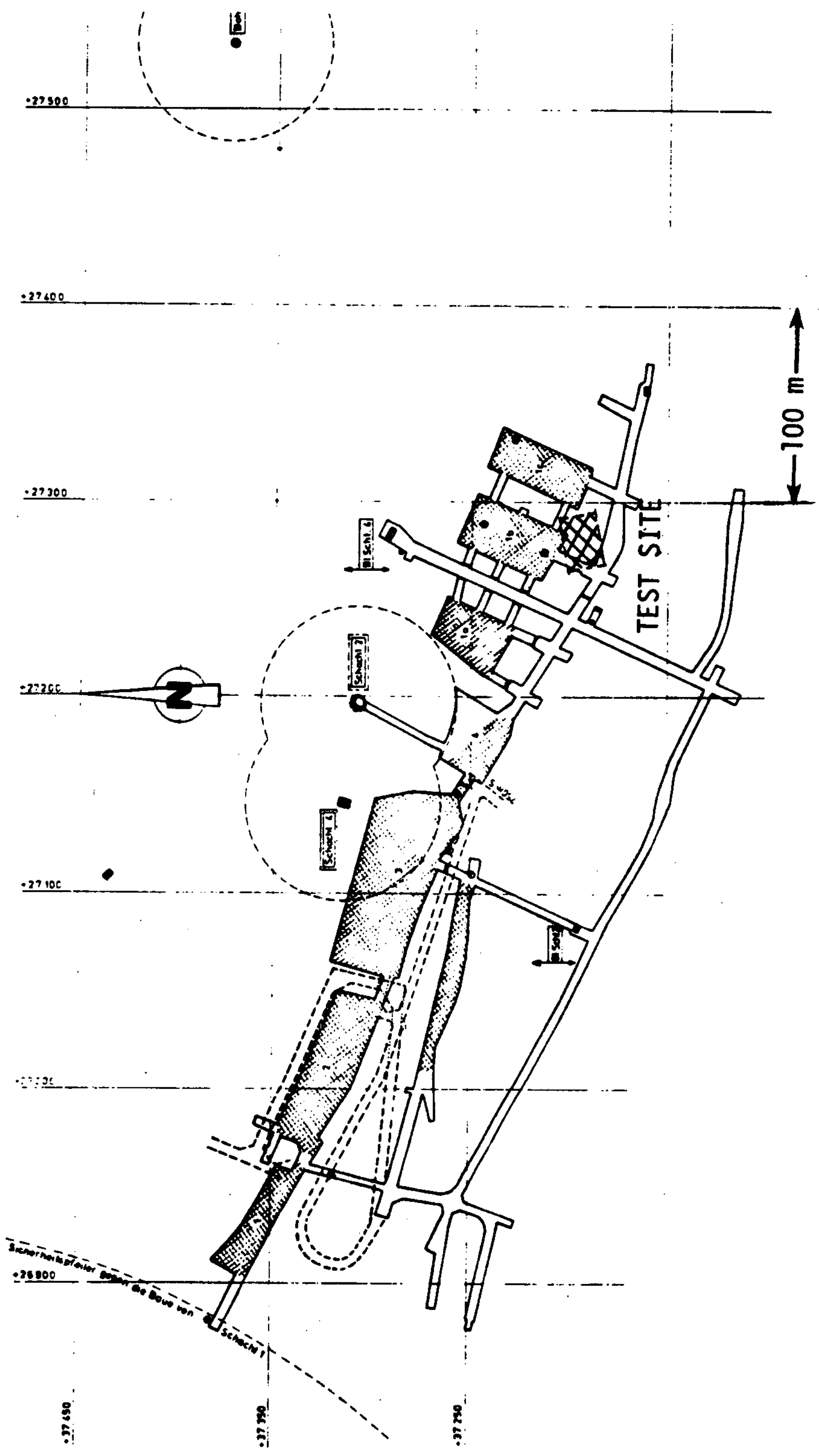

Figure 5-4. Mine Plan - 775 Meter Level

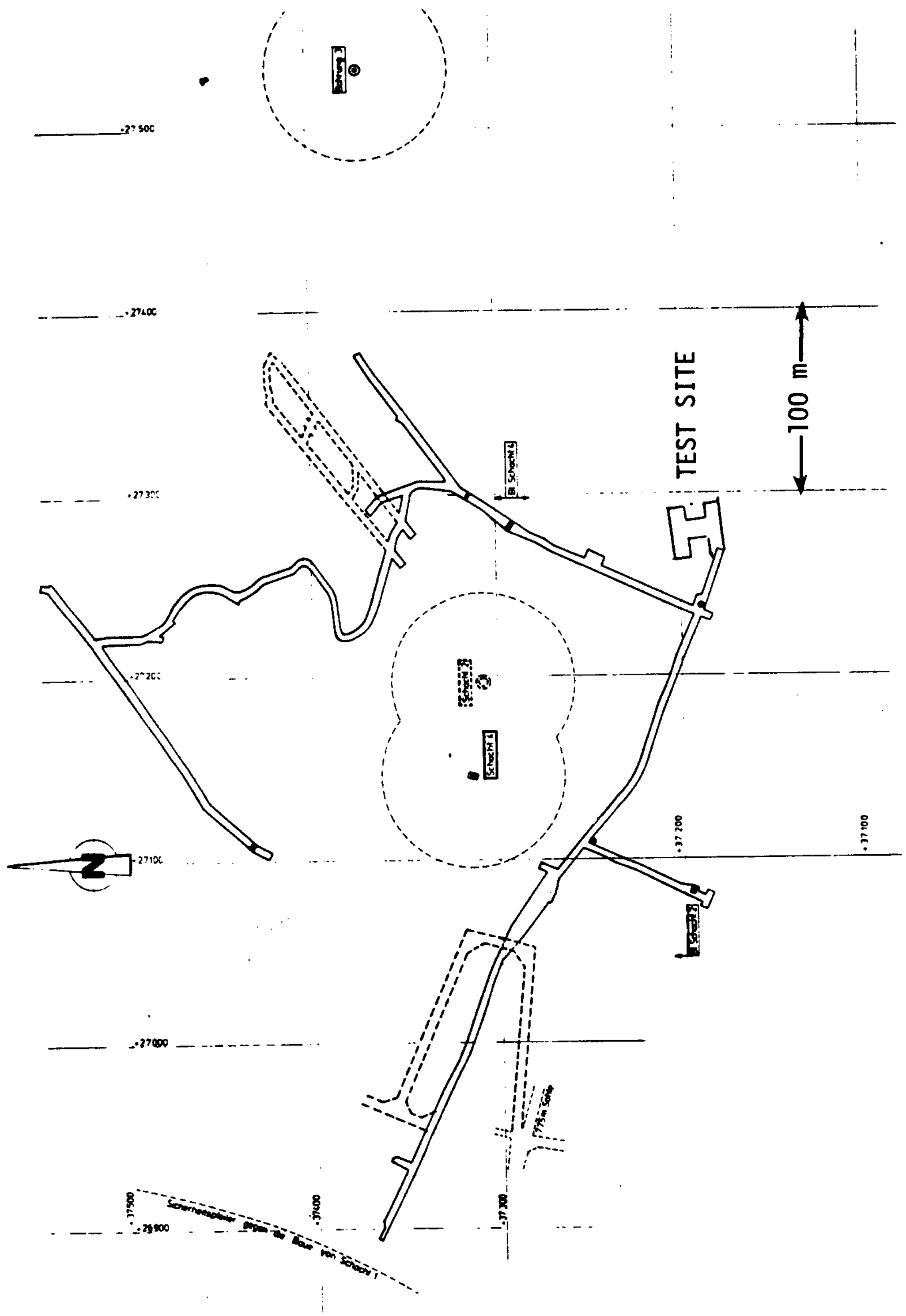

Figure 5-5. Mine Plan - 800 Meter Level

To prevent thermal interaction between experiments, it is calculated that minimum spacing between experiments must be 15 m (45 feet), see Section 6.2. Additionally, to minimize the effect of nonuniform stress conditions near unmined portions of the site, a minimum of 5 m (15 feet) is prescribed for the distance to the nearest wall, pillar, or pillar corner. Location of the experiments along the gallery centerline is essential. Section 6.10 indicates that the minimum spacing between parallel gallery centerlines should be 30 m.

Accessibility also puts constraints on mine layout and design. For example, entries must be capable of accommodating the vehicle used to transport materials. Likewise, sufficient overhead clearance must be provided to emplace the radiation simulator package and the test assembly which is estimated to be 5 m (16.4 ft) long. Easy accessibility for sample collection during tests is an important consideration as is sufficient instrumentation space to accommodate sensor outputs and heater controllers, etc.

An access entry will be excavated from the intersection of existing northwest-southeast and northeast-southwest cross-cuts at the 800-meter level in an approximate easterly direction. The suggested dimensions of this entry are 6 x 6 meters and it could be excavated either by drilling and blasting or by a continuous miner.

The individual test galleries (10 meters wide and 8 meters high) will be excavated parallel to the geological structure. The preferable mining method for the test galleries is a continuous miner to eliminate the potential salt damage from blasting.

Further constraints placed on mine layout are those associated with maximum sizes for entries which require a long term stand-up period. In addition, safety considerations require a layout which permits rapid access to radiation sources for removal.

Based on the above constraints and the desire to minimize tunnel dimensions, a Z-shaped layout similar to the one in Figure 5-6 is proposed. Orientations

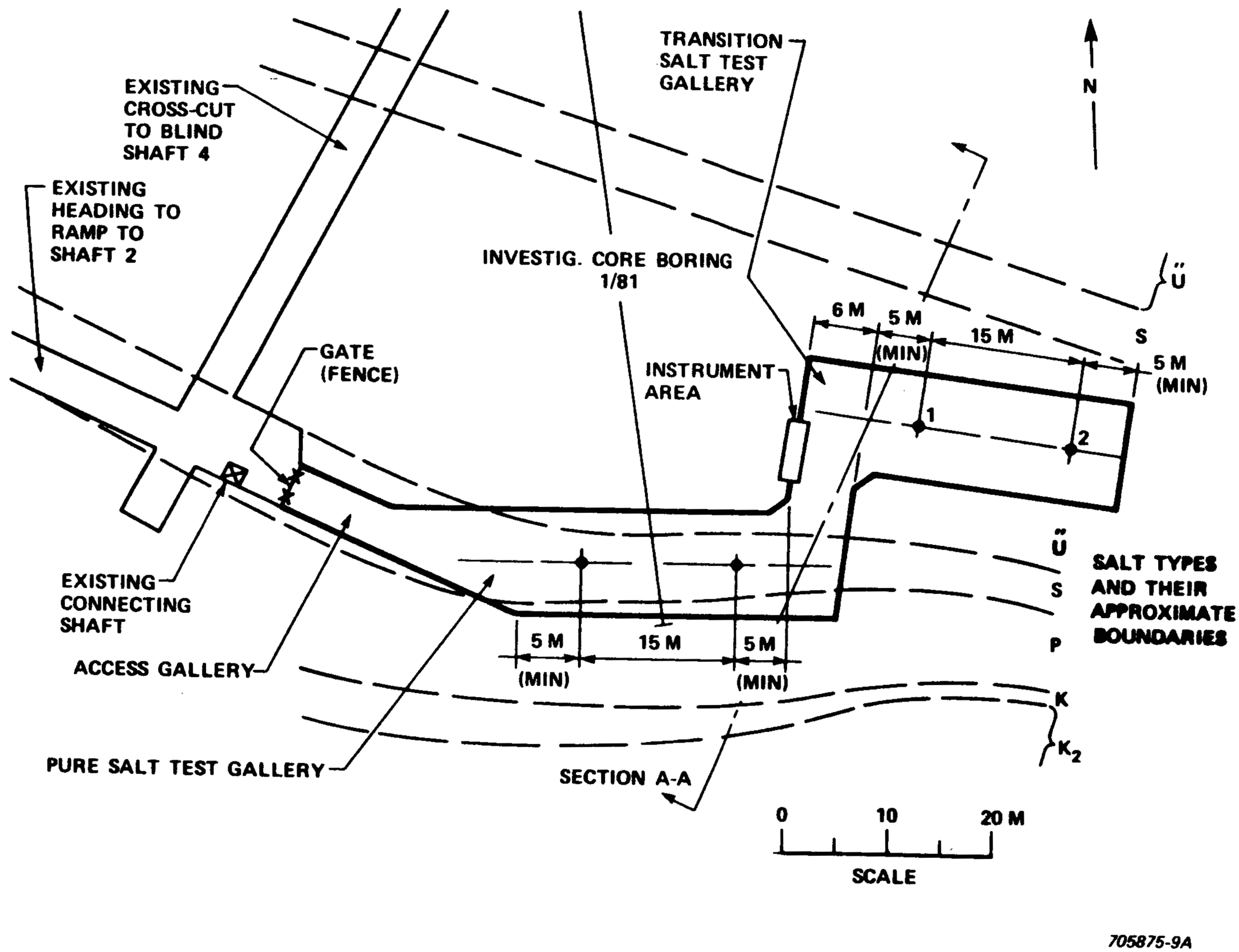

Figure 5-6. Proposed Z-Shaped Test Site Layout

of the two test chambers should be chosen to provide access to the most uniform salt possible in both salt types.

It is suggested that longer test galleries should be excavated to provide space for additional test sites which may or may not be utilized depending on the conditions and results at the planned four test sites.

All cables and tubing are routed next to the walls and between the wall and the test site are below floor level. The emergency diesel-generator must be located in the main drift rather than in the experiment area to satisfy mine safety requirements.

5.2 HARDWARE DESCRIPTION

The test assembly described in this section is shown in Figures 5-7 and 5-8. The assembly will be surrounded by a ring of guard heaters, as shown in Figure 5-9.

5.2.1 Design Features

The purpose of the brine migration hardware is to produce a salt formation environment which produces the thermal and radiation conditions desired. The hardware will be designed so conditions can be controlled and so that any brine migration activity stimulated by its presence can be detected and measured.

The following basic features have been considered in the design:

- Cobalt 60 will be used as the radiation source.
- Auxiliary heat and temperature control capability will be provided by tubular electrical resistance heaters.
- Instrumentation will include gauges for monitoring the deformation of the material forming the outer sleeve; thermocouples for observing the temperature of the heat source and for measuring the axial and radial temperatures of the outer sleeve and borehole; pressure detectors for indicating leakage at the outer sleeve; and moisture-collecting apparatus for measuring the migration of brine to the heat source.

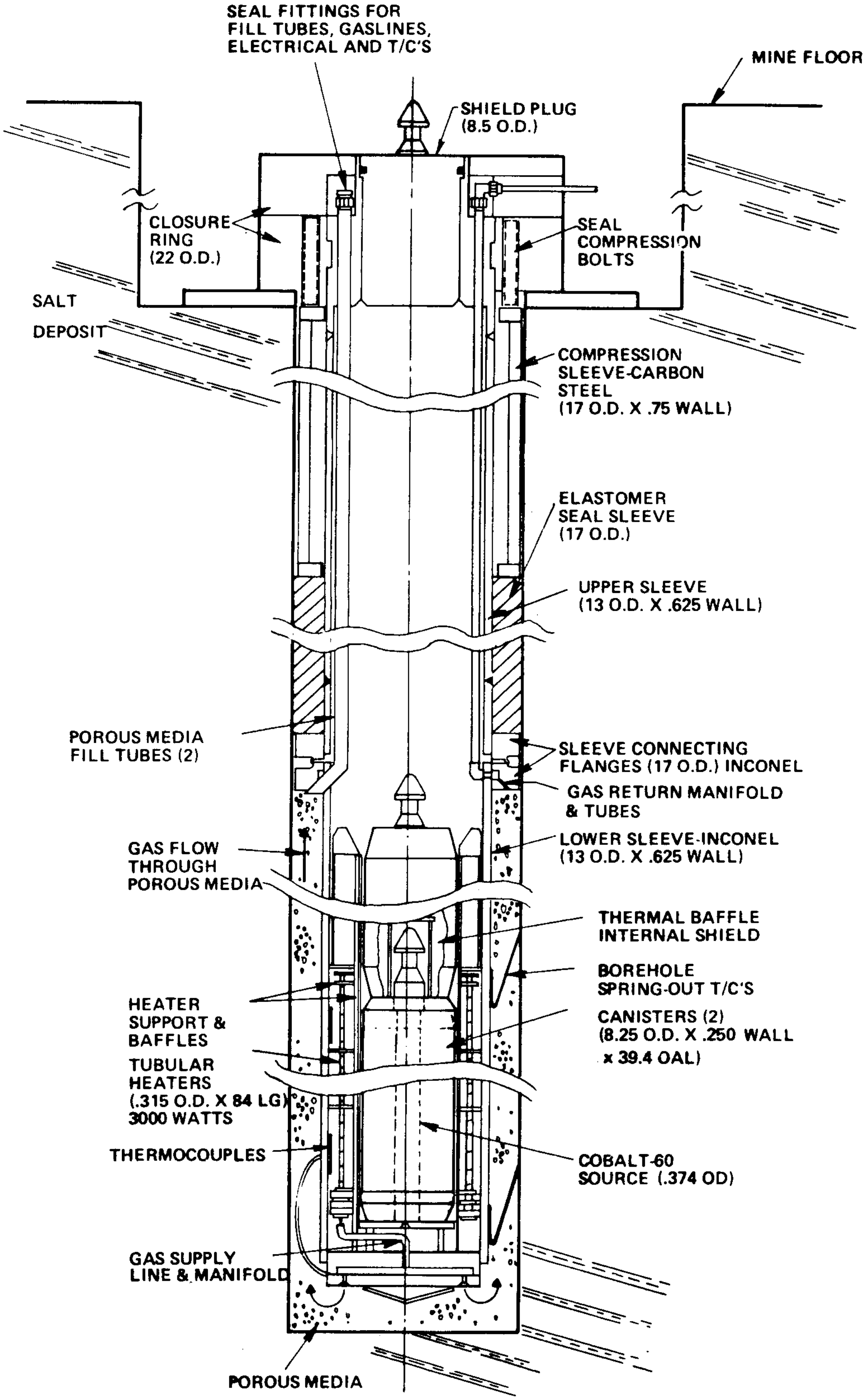

Figure 5-7. Cross Section of Brine Migration Test Assembly

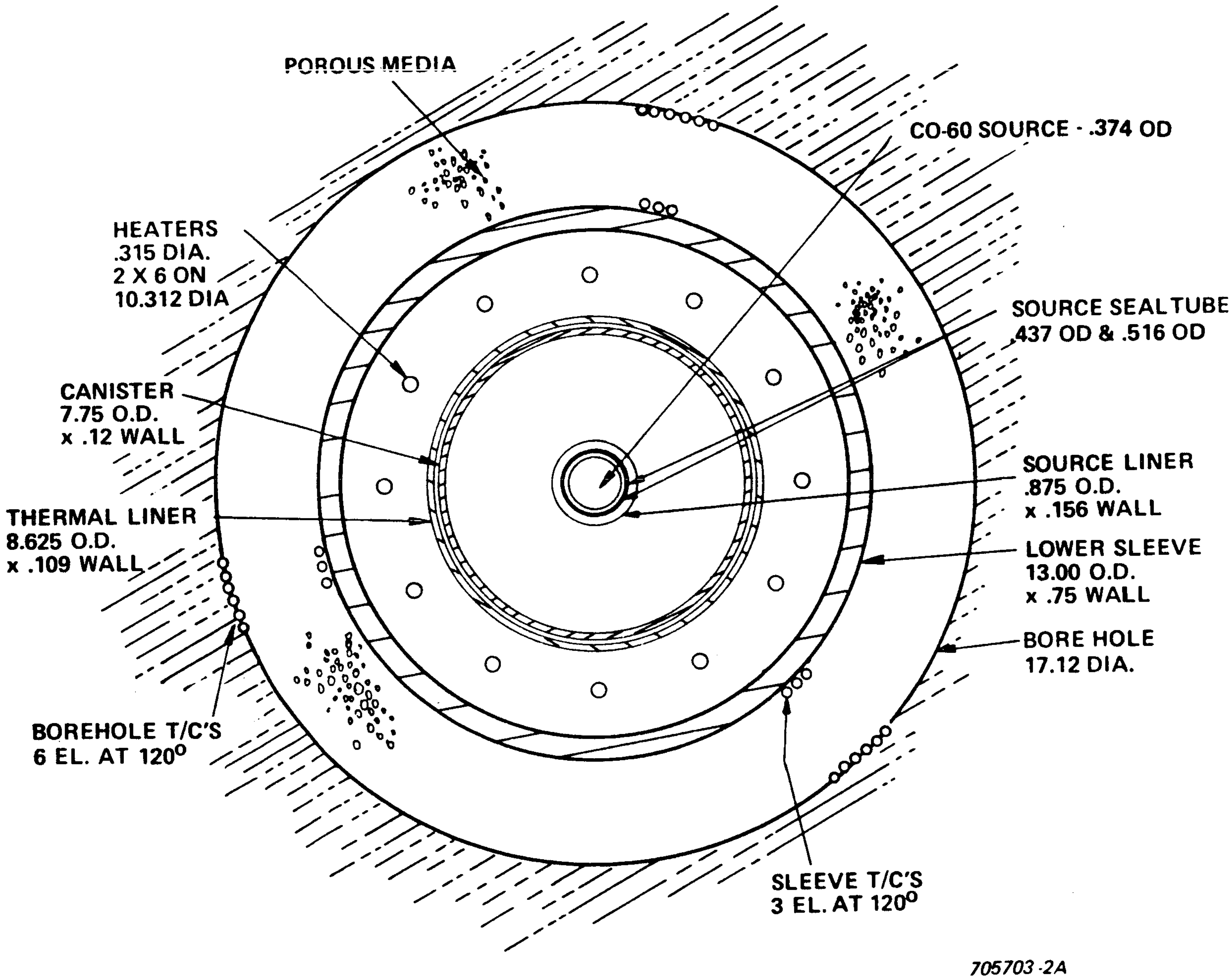

Figure 5-8. Horizontal Section of Test Assembly Near Heater Midline

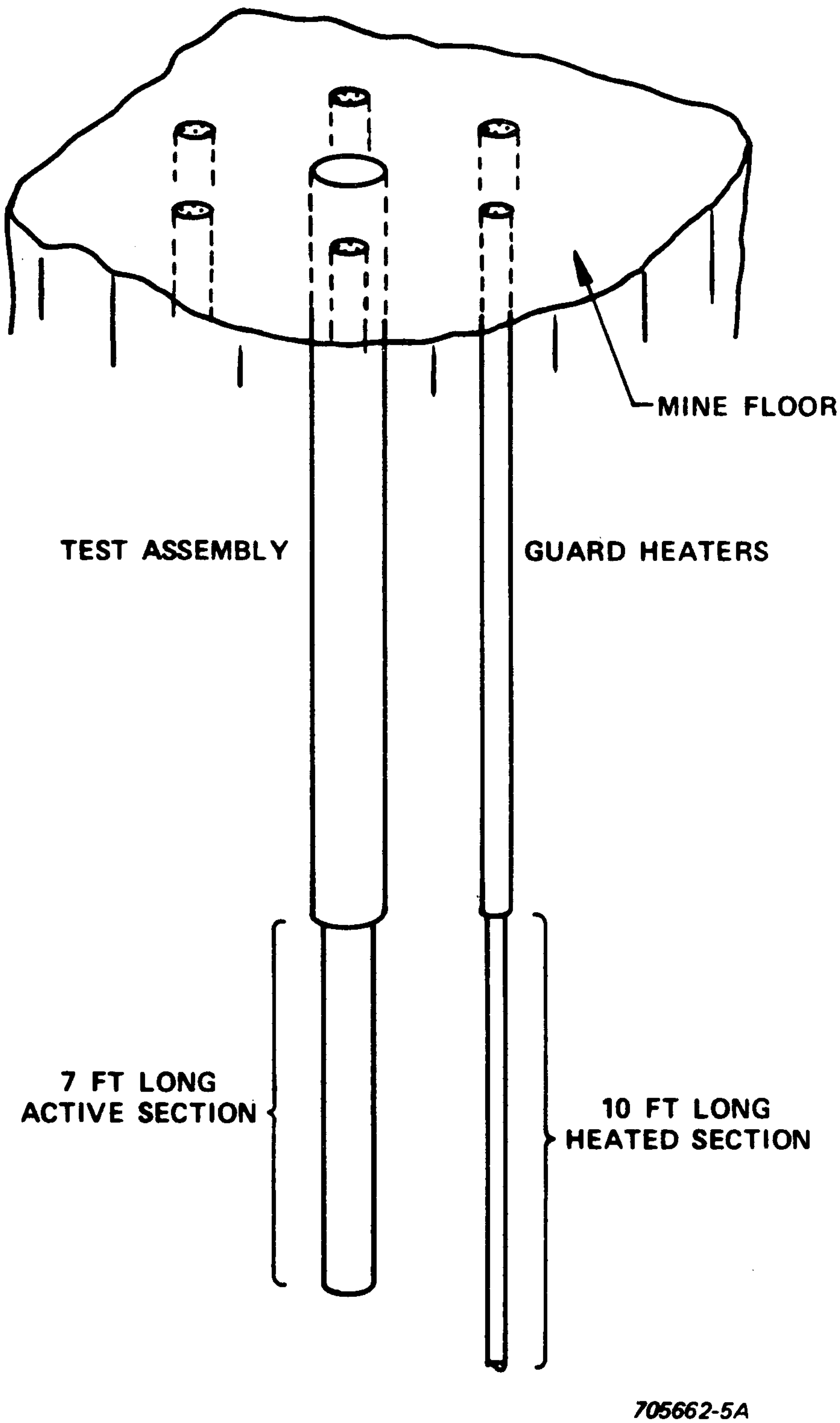

Figure 5-9. Test Site Overview

- A gas purge annulus for moisture collection will be maintained around the outer sleeve through use of a porous buffer layer.

- Moisture collection will be accomplished by circulating nitrogen in a closed system through the porous media and removing moisture absorbed in the gas with cold traps at the floor level.

- An elastomer seal will be used in the annulus above the test section to isolate the moisture-collecting zone.

- The radiation source will be isolated from the environment by a multi-barrier package.

- The canister containing the radioactive source will be retrievable using the grapple and transport equipment designed to place the canisters in the test assembly.

- The design of the test assembly will use the English system of units to reduce cost. Equipment interfacing with survace components such as electrical or tubing connections will be provided to metric specifications.

- The test assembly will provide sufficient radiation shielding to limit the average dose rate at the borehole closure to a maximum of 2.5 mrem/hour and as low as reasonably achievable when the source canisters are in their normal storage configuration.

- The sleeve assembly and seal will be a pressure boundary limiting leakage from the active test zone.

5.2.2 Test Assembly (Figure 5-7)

The test assembly is composed of an upper and lower sleeve assembly joined to an enlarged seal section to form the primary boundary to protect the test material from the pressure and corrosive effects of the salt environment. The sleeves are joined by welded joints at the seal section to form a continuous tubular assembly. Surrounding the upper sleeve and seal section is a caisson which is sealed and bonded to the salt borehole. A series of O-ring elastomer seals provide a seal between the caisson and the sleeve assembly seal section to isolate the lower test zone. The upper closure provides external termination of the interconnecting instrumentation, electrical, gas and fill lines between the lower sleeve and upper closure. Within the test assembly lower sleeve are two canisters containing the cobalt 60 sources. Surrounding the canisters is an electrical heater assembly consisting of two redundant sets of six tubular heaters each extending approximately 15 cm (6 in.) beyond the upper end of the stacked canisters. Above the top canister is an assembly containing thermal insulation and shielding to protect the elastometer seals and to limit heat transfer to the upper sleeve. Thermocouple instrumentation extending from the upper sleeve closure measures temperatures on the outside diameter of the lower sleeve at three elevations and three azimuthal positions. Thermocouples also extending from the caisson contact the borehole wall to measure test zone temperature at six elevations and three azimuthal positions. The surface of the test assembly is shielded by a shield ring surrounding the upper sleeve closure transition and an integral shield plug which limits the radiation to a low level at the mine floor. The sleeve and heater assemblies are delivered as a single unit approximately 5 m (16.4 ft.) long. They are designed for insertion into the caisson lining the 43.5 cm (17.13 in.) diameter borehole. Following insertion, the annulus between the borehole and the lower sleeve is filled with granular media through fill tubes routed from the upper closure.

5.2.2.1 Sleeve Assembly (Figure 5-7)

The sleeve assembly consisting of a lower and upper sleeve and closure provides the containment housing for the source canisters, tubular heaters and internal shield and thermal baffle. The sleeves are 13.00 inches (33 cm) in diameter with a 0.75 inch (1.9 cm) wall. The lower sleeve tube, seal section, and lower end gas manifold are constructed of Inconel 600. The upper sleeve and closure is carbon steel. The transition weld is above the elastomer seals and is, therefore, protected from potential galvanic corrosion. Inconel 600 was chosen for this application because it is resistant to brine corrosion, is relatively available, easy to fabricate, and inexpensive when compared to other potential materials.

The lower sleeve assembly includes an end plate containing the gas inlet manifold to the porous media and the structural support for the heater assembly. Extending from the closure, down the outside diameter of the upper sleeve, and terminating at axially drilled passages in the center seal section are two porous media fill tubes, three thermocouple guide tubes, and one gas exit sampling tube. The fill tubes are straight lengths of 1/2 inch Schedule 40 pipe (1.6 cm ID) (preliminary), and the gas and thermocouple tubes are 1/4 inch Schedule 40 pipe (.9 cm ID). The Inconel 600 tubes are socket welded to the seal sections. Test zone pressure isolation is maintained at the closure end by compression seal fitting for the thermocouple sheaths and compression caps for the fill tubes. The seal section is 15.375 inches (39.0 cm) in diameter, 3.62 inches (9.2 cm) long with four 0.210 inch (5.3 mm) diameter O-ring seals. The candidate material for the O-ring seals is ethylene propylene diene which meets the service requirements for temperature, environment, and low compression set. The annulus between the seals will be pressurized with nitrogen to reduce the diffusion leakage of the gas from the test zone.

5.2.2.2 Heater Assembly (Figure 5-7)

Contained within the inner periphery of the lower sleeve is a tubular heater assembly. This assembly consists of two sets of six 0.315 inch (0.8 cm) diameter heaters for redundant operation. The heaters are approximately 74 inches (1.9 m) long, and each has a thermal rating of 3,000 watts. Several thermal baffles along the length of the assembly restrict natural convection and reduce distortion of the thermal profile. The heater assembly support tube also serves as a guide for the radioactive source canisters. The annulus above the heaters which extends to the seal section area contains thermal insulation and shielding. This, along with a center assembly containing insulation and shielding resting on top of the canisters, protects the external elastometer seals and limits heat transfer to the upper sleeve volume. Located at the midplane of the heater assembly is a deformation gage. This gage will detect possible deformation of the sleeve due to the lithostatic pressure of the salt, permitting removal of the source canisters before sleeve deformation becomes excessive.

5.2.2.3 Seal and Seal Caisson (Figure 5-7)

Surrounding the test assembly upper sleeve and seal section is a caisson which is sealed and structurally bonded to the salt borehole. The caisson is

86 inches long (2.2 m), extending from near the entrance to the borehole, and has an outside diameter of 16.38 inches (41.6 cm) and an internal sealing diameter of 15.375 inches (39.0 cm). The lower 6 inches (15.2 cm) of the caisson is enlarged to a diameter of 17.00 inches (43.2 cm) to provide additional rigidity for the internal seals and to restrict the flow of the castable seal material. The enlarged seal section is made from Inconel 600 while the remainder of the caisson is carbon steel.

The annulus between the borehole and caisson is filled with castable seal system. Candidate materials for this castable seal are polysulfide and epoxy. The seal will be required to retain the 60 psi (0.4 MPa) test zone gas pressure and support the total borehole axial pressure load. A flange section at the upper end of the caisson provides a bolted connection to connect the test assembly and caisson.

Extending below the caisson are thermocouples which will contact the test zone borehole wall at five elevations and three azimuthal positions. Three thermocouples at one elevation will also be located in the enlarged sections of the caisson to record the temperature in the area of the seals. The thermocouple sheaths pass through the castable seal and terminate at the test assembly closure.

5.2.2.4 Closure (Figure 5-7)

The test assembly closure consists of the outer shield ring, upper sleeve transition, and shield plug. These carbon steel components, along with the internal shield, are intended to reduce the surface radiation dose rate to a maximum of 2.5 mrem/hr under normal canister storage conditions. The shield plug will have a maximum diameter of 8.25 inches (21 cm) and a standard handling pintle for grappling and handling by the surface transfer cask.

5.2.2.5 Canister and Source (Figure 5-10)

The canisters containing the radiation source are approximately 39 inches (1 m) long due to constraints imposed by the transport vehicle. They will be fabricated from 7.75 inch (19.7 cm) OD by 0.120 inch (3 mm) wall carbon steel pipe

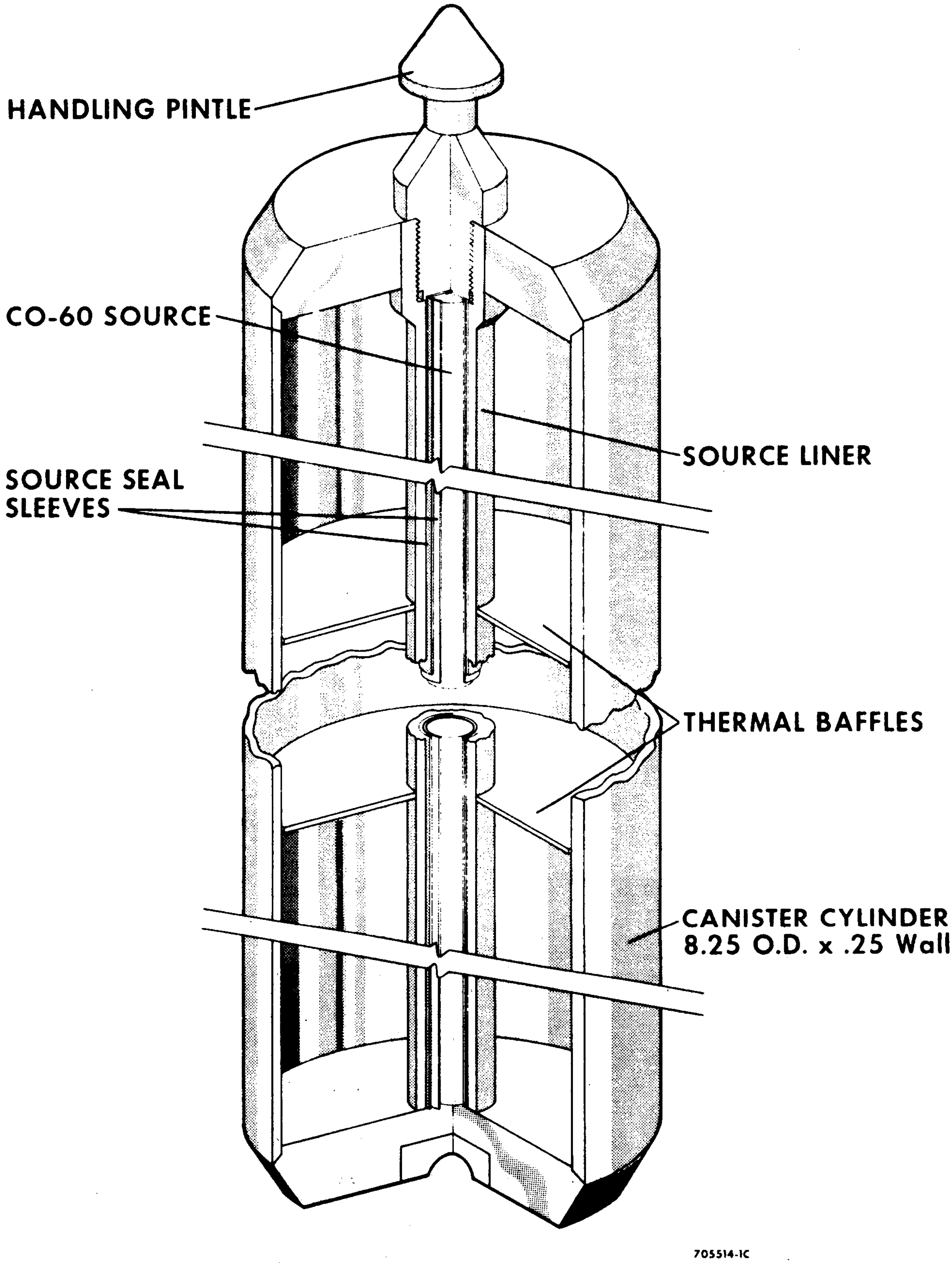

Figure 5-10. Radioactive Source Canister Assembly

with tapered end plates and handling pintle. The sources will be located in the canister by a concentric cylinder, 0.6 inch (1.5 cm) ID. The source will be cobalt 60, see Section 5.4.3. The empty volume of the canister will be filled with fiberglass insulation or baffles to reduce convection within the test assembly.

The source will be loaded into the canister in a hot cell area by the source manufacturer, and the canister will be closed by a simple mechanized closure. Dummy canisters will be provided for the nonradioactive experiments to fill this area and maintain the same thermal environment for these tests.

5.2.2.6 Porous Medium (Figure 5-8)

As described in previous sections, the annulus between the borehole and lower sleeve is filled with a porous medium for the collection of water and gases which may be generated during the test and to support the borehole wall. Desirable material properties that have been identified for this application are:

- Good compressive strength at 300°C after exposure to brine, radiation, and heat
- High thermal conductivity to enhance heat transfer to the borehole wall
- Nonreactivity with water and brine at the design conditions
- Good pourability
- Little compaction under load
- Nonclogging with residue from evaporated brine
- Low density to limit radiation attenuation to the geologic salt

A number of materials for this application have been surveyed which resulted in a recommendation that alumina (Al_2O_3) is most suited for the brine migration test collection media after consideration of material properties, stock availability, and cost. The material is available in 3/16 to 1/4 inch

(4.5 to 6.3 mm) diameters, which should provide good pourability and insignificant clogging of the gas collection manifolds. Other materials, including carbon and graphite, are being considered as backups. These materials will be tested to assure that they will satisfy the requirements. There is evidence that alumina may react to an excessive degree with the water in brine, but reaction with water vapor may be limited. This will be verified by the testing.

5.2.3 Guard Heaters (Figure 5-9)

Peripheral heaters will be placed in an octagonal pattern around the canister location 59 inches (1.5 m) from the centerline of the test assembly. The guard heaters will extend approximately 2.5 feet (0.8 m) below and above the active region of the lower sleeve. These heaters are intended to modify the thermal gradient around the lower sleeve and improve the storage simulation.

5.2.4 Placement and Retrieval (Figure 5-11)

To prevent radiation exposure to the personnel during emplacement or retrieval of the source canisters at the test site, it will be necessary to utilize a transport shield with an integral lower valve and a separate shielded valve adapter which is positioned over the test assembly closure. This equipment will be provided by the FRG and is currently being designed. The figure shows an early conceptual design.

The valve adapter is placed over the closure of the test assembly to be filled. The adapter limits radiation streaming from around the closure during installation or removal and during the interval when the closure shield plug is not in place. The transport vehicle is used to place the shield containing the source over the valve adapter that has been mated with the test assembly closure. The valves in the transport shield and the valve in the adapter will be opened and the canister lowered into the test position. The canister will be released by the grapple and the grapple withdrawn through the transport shield. To avoid streaming, the adapter valve will be closed before the transporter will be removed.

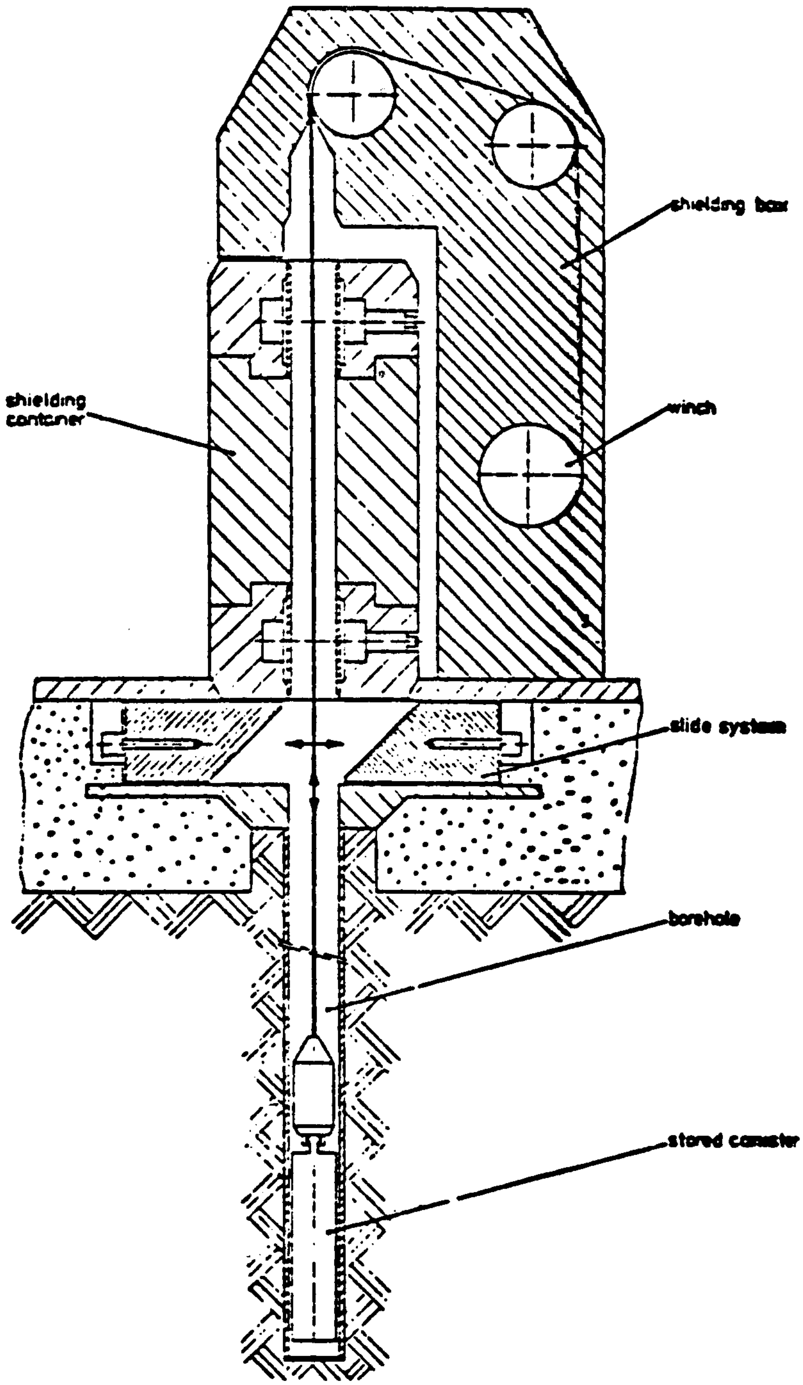

Figure 5-11. Arrangement for Installing and Removing Radioactive Source Canisters - Preliminary

The second canister will be placed in the same manner. The thermal baffle and internal shield and then the closure shield plug (Figure 5-7) will be emplaced using the transport shield and grapple with a similar sequencing of the valves. After the shield plug is in place, the transport vehicle will be removed. The valve adapter will normally remain in place to facilitate rapid source retrieval in the event of a mine accident, but may be removed if access to the test assembly is required during the test. Retrieval will be the reverse order of the above procedure, resulting in removal of both canisters with radioactive sources to a preselected temporary storage site.

5.2.5 Removal of Test Hardware

On conclusion of the test and removal of the source canisters, the test assembly will be removed as a unit to provide access to the porous media and to the salt in contact with the active zone during the test. The closure outer shield ring will be removed and the bolts attaching the test assembly to the seal caisson disconnected. A support ring will be placed around the test assembly with a support beam extending across the centerline of the test position. Tension bolts will be connected to the top surface of the test assembly closure and passed through clearance holes in the support beam. Nuts placed on the tension bolts will be activated to apply a tension load on the test assembly and break it free before a hoist is used to lift the test assembly free of the hole in the floor of the salt mine. The seal caisson will not be removed.

5.3 INSTRUMENTATION

5.3.1 Measurement Requirements List (MRL)

The MRL (see Table 5-1) tabulates the measurements by parameter and location, identifies the type of sensing function, and indicates whether a surface alarm is required for a particular condition.

The borehole gap pressure, pump outlet pressure, and dry nitrogen pressure measurements, and the flow switch and level switch are all associated with the moisture collection system (see Figure 5-12).

TABLE 5-1. MEASUREMENT REQUIREMENTS LIST

MEASUREMENT DESCRIPTION	RANGE	ACCURACY	SENSOR TYPE	TEST ASSEMBLY 1	2	3	4	LOCAL INDICATOR ONLY	SURFACE ALARM			
1. CURRENT												
Heater Circuits	30 amps (RMS)		Current Xdcr	2	2	2	2		X			
	75 amps (RMS)		"	2	2	2	2		X			
2. DISPLACEMENT												
Lower Sleeve												
(1) Elev. -184.13 θ = 30°	0 to -1.6 mm		Displace Xdcr	1	1	1	1		X			
θ = 120°	"		"	1	1	1	1		X			
θ = 210°	"		"	1	1	1	1		X			
θ = 300°	"		"	1	1	1	1		X			
(2) Elev. -192.13 θ = 30°	"		"	1	1	1	1		X			
θ = 120°	"		"	1	1	1	1		X			
θ = 210°	"		"	1	1	1	1		X			
θ = 300°	"		"	1	1	1	1		X			
3. FLOW												
Moisture Collection Line	0.1 L/min.		Flow Switch	1	1	1	1		X			
4. LEVEL												
Water Collection Container	Adjustable		Level Switch	1	1	1	1		X			

TABLE 5-1. MEASUREMENT REQUIREMENTS LIST (Continued)

MEASUREMENT DESCRIPTION	RANGE	ACCURACY	SENSOR TYPE	TEST ASSEMBLY 1	2	3	4	LOCAL INDICATOR ONLY	SURFACE ALARM			
5. TEMPERATURE												
5.1 Central Borehole Wall			Type "K",									
(1) Elev. -142.13 θ = 0°	30°C - 300°C		Thermocouple	1	1	1	1		X			
θ = 120°	"		"	1	1	1	1		X			
θ = 240°	"		"	1	1	1	1		X			
(2) Elev. -158.13 θ = 0°	"		"	1	1	1	1		X			
θ = 120°	"		"	1	1	1	1		X			
θ = 240°	"		"	1	1	1	1		X			
(3) Elev. - 188.13 θ = 0°	"		"	1	1	1	1		X			
θ = 120°	"		"	1	1	1	1		X			
θ = 210°	"		"	1	1	1	1		X			
(4) Elev. -234.13 θ = 0°	"		"	1	1	1	1		X			
θ = 120°	"		"	1	1	1	1		X			
θ = 240°	"		"	1	1	1	1		X			
(5) Elev. -234.13 θ = 0°	"		"	1	1	1	1		X			
θ = 120°	"		"	1	1	1	1		X			
θ = 210°	"		"	1	1	1	1		X			
5.2 Lower Sleeve												
(1) Elev. -158.13 θ = 0°	"		"	1	1	1	1		X			
θ = 120°	"		"	1	1	1	1		X			
θ = 240°	"		"	1	1	1	1		X			

TABLE 5-1. MEASUREMENT REQUIREMENTS LIST (Continued)

MEASUREMENT DESCRIPTION	RANGE	ACCURACY	SENSOR TYPE	TEST ASSEMBLY 1	TEST ASSEMBLY 2	TEST ASSEMBLY 3	TEST ASSEMBLY 4	LOCAL INDICATOR ONLY	SURFACE ALARM			
5.2 Cont'd. (2) Elev. -188.13 θ = 0°	30°C - 300°C		Type "K", T/C	1	1	1	1		X			
θ = 120°	"		"	1	1	1	1		X			
θ = 240°	"		"	1	1	1	1		X			
(3) Elev. -218.13 θ = 0°	"		"	1	1	1	1		X			
θ = 120°	"		"	1	1	1	1		X			
θ = 210°	"		"	1	1	1	1		X			
5.3 Guard Heater Sleeve												
Elev. -139.13	"		"	4	4	4	4		X			
Elev. -188.13	"		"	4	4	4	4		X			
Elev. -237.18	"		"	4	4	4	4		X			
5.4 Field Temp. Probe												
(1) θ = 0°/Elev. -99.55	30°C - 150°C		"	1	1	1	1					
-139.13	"		"	1	1	1	1					
-188.13	"		"	1	1	1	1					
-218.13	"		"	1	1	1	1					
-276.71	"		"	1	1	1	1					
(2) θ = 135°/Elev.-99.55	"		"	1	1	1	1					
-139.13	"		"	1	1	1	1					
-188.13	"		"	1	1	1	1					
-218.13	"		"	1	1	1	1					
-276.71	"		"	1	1	1	1					

MEASUREMENT DESCRIPTION	RANGE	ACCURACY	SENSOR TYPE	TEST ASSEMBLY 1	2	3	4	LOCAL INDICATOR ONLY	SURFACE ALARM			
5.4 Cont'd. (3) θ = 225°/Elev. -99.55	30°C - 150°C		Type "K", T/C	1	1	1	1					
-139.13	"		"	1	1	1	1					
-188.13	"		"	1	1	1	1					
-218.13	"		"	1	1	1	1					
-276.71	"		"	1	1	1	1					
5.5 Caisson												
Elev. -126.62 θ = 0°	30°C - 300°C		"	1	1	1	1					
θ = 120°			"	1	1	1	1					
θ = 240°			"	1	1	1	1					
5.6 Refrigerator			Temp. Switch						X			
6. POWER												
Heater Power Controller			Watt/Watthour Meter	4	4	4	4	X				
7. PRESSURE												
Borehole Gap			Press Xdcr	1	1	1	1		X			
Pump Outlet			"	1	1	1	1					
Test Assembly Internal			"	1	1	1	1		X			
Dry N_2 Purge Gas			Press Gage	1	1	1	1	X				

TABLE 5-1. MEASUREMENT REQUIREMENTS LIST (Continued)

MEASUREMENT DESCRIPTION	RANGE	ACCURACY	SENSOR TYPE	TEST ASSEMBLY 1	2	3	4	LOCAL INDICATOR ONLY	SURFACE ALARM			
8. STRAIN (SALT STRESS)												
Lower Outer Sleeve												
Elev. -188.13												
θ = 81°/Circ			Strain Gage	1	1	1	1		X			
Long			"	1	1	1	1		X			
θ = 201°/Circ			"	1	1	1	1		X			
Long			"	1	1	1	1		X			
θ = 321°/Circ			"	1	1	1	1		X			
Long			"	1	1	1	1		X			

MOISTURE COLLECTION SYSTEM

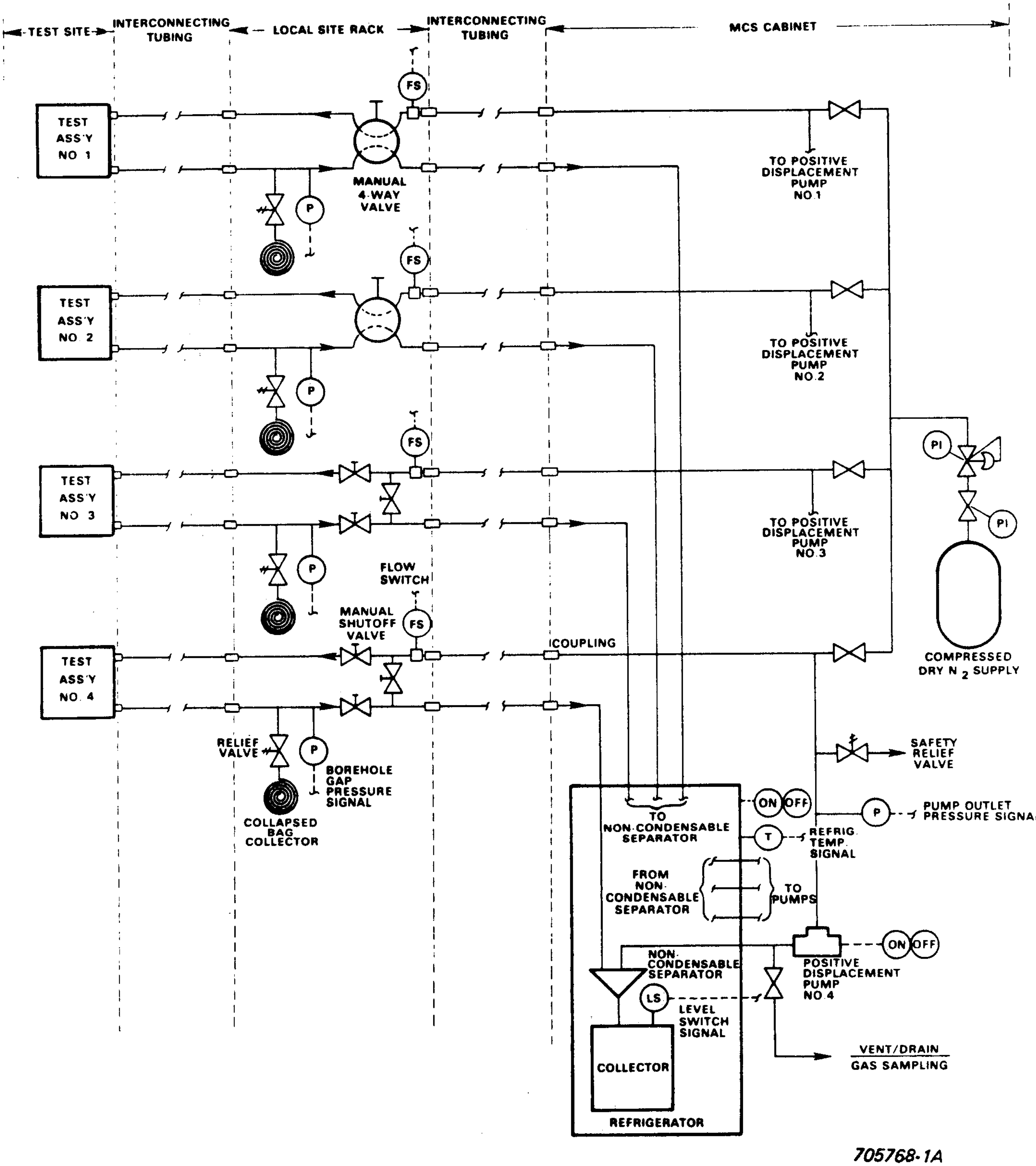

Figure 5-12. Schematic of Moisture Collection System

The borehole wall temperature measurements inside the central borehole are made at five elevations and three azimuthal locations for a total of fifteen measurements per site.

The lower inner sleeve temperature measurements are made at three elevations, and three azimuthal locations for a total of nine measurements per site. In addition the temperature of the caisson seal is measured at three azimuthal location.

The temperature probe measurements are made at three azimuthal locations about the center of each test site and five elevations, for a total of fifteen measurements per site. The temperature of the outside of four of the guard heaters is measured at three elevations. The probes and the guard heaters are all located at the same radial distance from the test site center.

There are four current measurements per test site. Two instruments monitor power to the central borehole heater rods while the others monitor power to the guard heaters. This measurement is to detect heater failure.

Displacement sensors or switches will be placed inside the lower sleeve to monitor for initiation of collapse. As presently configured, this parameter will be monitored at two elevations. At the present time, it is not known how this parameter will be monitored, and implementation difficulties may require several sensors/switches at each output elevation.

Radiation dosimetry, if included, would be installed in a groove in the salt around the central borehole.

5.3.2 Sensors

5.3.2.1 Temperature

The general environment consists of steam, saturated brine, and salt, with a temperature range of 25°C to about 350°C (80 to 670°F). The Chromel-Alumel (Type K) metal sheathed and grounded junction thermocouples were selected to make all temperature measurements. These thermocouples would be fabricated with premium grade T/C wire and insulated with magnesium oxide inside an Inconel 600 sheath. It is noted that RE/SPEC has had success using a similar clad thermocouples with Chromel-Alumel (Type K) elements at Avery Island, (Krause, 1983).

Thermocouples on the outer sleeve are routed down a groove in the external surface of the outer sleeve to the point of measurement. A cover plate, welded along one side only, will cover the cables in the groove and protect them from damage.

Thermocouples to monitor borehole wall temperatures are attached to a support structure which is assembled to the caisson. This structure supports three vertical bundles of thermocouples (at circumferential intervals of 120°). One thermocouple exits each bundle at each of five measurement elevations. A spring clip provides spring loading to assure firm contact between the thermocouple and the borehole wall. This structure will be installed prior to installation of the test assembly and filling the annulus with beads. Three carbon steel probes will be assembled with three thermocouples each to monitor the temperature field around each test site. These Inconel clad thermocouples are also encased in Teflon to avoid corrosive incompatibility with the carbon steel. The structure also provides spring loading to assure that the thermocouples make firm contact with the borehole wall.

Thermocouples on the guard heaters are attached on the heater assembly OD at three elevations. To avoid corrosion problems (Inconel T/C sheath and carbon steel pipe) the thermocouples are jacketed in Teflon.

5.3.2.2 Pressure

Pressure measurements are made for the borehole gap, the test assembly internal volume, and the moisture collection system pump outlet. The actual environment for the sensor electronics in each of these cases is mine ambient conditions. The borehole gap pressure measurement (see Figure 5-12) for the pressurized sites may expose the pressure sensors to 200°C temperatures and steam, however this is not regarded as very severe.

Local pressure gauges are provided on the compressed dry nitrogen gas cylinder along with shutoff and throttling valves. This gas would be used for purging and filling the moisture collection system (MCS), including tubing and borehole gap, prior to startup. It would also be used for repurging the pressure lines to the pressurized sites immediately prior to their release.

5.3.2.3 Displacement Transducer/Switch

This measurement is intended to detect initiation of collapse of the lower sleeve. Environmentally qualified weldable strain gauges will be installed on cantilever beams to monitor lower sleeve radial deformation.

This location requires sensors that can remain reliable over a two-year period while exposed to ambient temperatures as high as 350°C (670°F). Shielding is provided for radiant heat from the heater elements which may operate at up to 600°C (1100°F). The environment also includes gamma radiation ($\sim 12 \times 10^8$ rads integrated dose over two year period).

Some strain gauge output drift is expected during the two year period, especially during startup. However the device is intended as a go/no go gauge and will be designed to produce a signal significantly above the drift level.

5.3.2.4 Current

There are eight current measurements per test site. Two measurements are made on each power controller output. One measurement is output to the data acquisition system to monitor changes in the output power (failure detection). The other measurement outputs to a panel mounted kilowatt/kilowatt-hour meter.

5.3.2.5 Gamma Radiation Rate/Dose

No compact radiation detector has been located which is usable at the temperatures and doses anticipated for this test. Since the dose can be calculated reasonably well and there is no need for high accuracy measurements, no radiation dose measurements will be made in the test zone.

5.3.3 Data Acquisition System (DAS) (Figure 5-13)

The front end of the DAS provides input module cards, each of which can accept eight or more input channels. These cards provide the basic signal conditioning necessary to convert each type input (volts, millivolts, milliamps and ohms) into a precisely scaled DC voltage. A temperature reference junction is provided for thermocouple inputs to permit correction for ambient temperature.

The remote scanner card frame provides slots for up to ten input module/multiplexer cards. Each remote scanner is controlled by the DAS to sequence through all of the multiplexer channels, and output each to the Data Logger.

At the Data Logger, the analog signal level is converted to a digital signal, processed for any required mathematical manipulations (e.g., conversion to engineering units) and transferred to a buffer. Data can be output in engineering units on a paper or foil-type tape, output to a remote printer, or stored on magnetic tape for further evaluation.

The Data Logger will be directly programmed at an integral keyboard, with the ability to have portions of the program remotely modified (at a remote keyboard).

As presently configured, the Data Logger system would be located in the vicinity of the test sites. The Data Logger is equipped with an RS232C communication port which will transmit and receive data and commands to and from the surface. The communications link includes modems to permit data transmittal over one or more twisted, shielded wire pair cables or telephone lines. The remote keyboard and printer, and magnetic tape system would be located in the above ground facility.

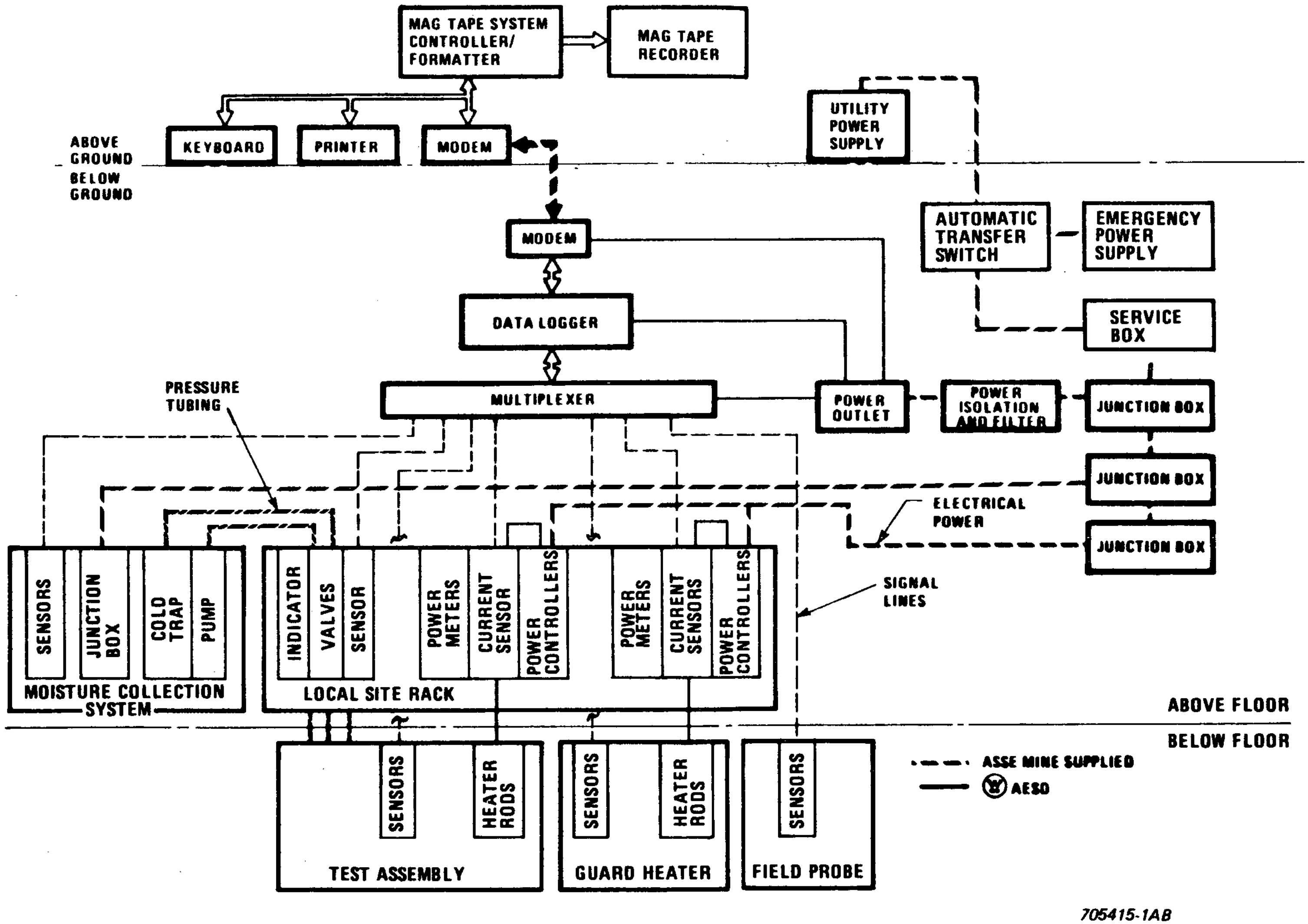

Figure 5-13. Block Diagram of Data Acquisition System

5.3.4 Moisture Collection System (MCS)

The MCS (see Figure 5-12) consists of the following items for each test site:

- Positive displacement pump to circulate the moisture carrier gas through the collection loop;
- Noncondensable separator which permits liquids to drain into a collector while noncondensables continue to circulate through the system;
- Collector container;
- Level switch installed on each collector container;
- Flow switch;
- A four-way valve or three manual shutoff valves;
- Two relief valves;
- Manual valve for a vent/drain/gas sampling line;
- Two pressure transducers - one on the test assembly outlet line and the other monitoring the pump outlet pressure;

For the overall system there will also be:

- One cold trap with sufficient capacity to refrigerate all four collection loops;
- Thermostatic temperature control on the refrigerator;
- Electrical switches and control panel for applying power to the cold trap as well as to the process pump motors;
- Cylinder of compressed dry nitrogen gas (for flushing and charging operations).

A moisture collection capability is required for each test site. Accordingly, two pressure lines (input and output) are built into each test assembly. The lines are ported at the bottom of the lower sleeve and at the bottom of the caisson, respectively. The lines pass through a seal block at the top of the test assembly and are routed to an adjacent local site rack. For unpressurized sites the rack supports a relief valve, a pressure transducer, and a manual four-way valve. An emergency container is also provided on the relief valve outlet so that exhausted gas and water is not lost. Pressurized sites will have a similar rack except for using a three manual shutoff valve arrangement instead of the four-way valve. Long pressure lines join each of these racks with the central moisture collector rack.

5.3.5 Heater Power Control

Four heater power controllers will be required for each test site. One controller regulates the power to the six heater rods located in the test assembly (heater rods are wired in parallel), while the second regulates power to the eight guard heater rods (also wired in parallel). Similarly, the remaining two controllers regulate power to backup heater rod groups which are built into the test assembly and guard heaters. The backup system will only be required in the event of a failure in the primary system. The heater power controllers will use two phase-angle fired power thyristors, which are fired alternately each half cycle.

The controllers would be equipped with voltage feedback control which automatically adjusts the output for any change in input voltage. This is accomplished by adjusting the timing of the power conduction trigger pulses. For instance, if operated at 50 percent power (90° conduction angle) output with 220 VAC input voltage and the input voltage drops to 190 VAC, the timing of the trigger pulses increases the conduction angle to keep the output voltage the same. Adjustments for variations in heater resistance which will occur during heatup will be performed manually by observing power meter indications.

5.4 RADIATION SOURCE

The radiation spectrum from spent fuel peaks in the range of 0.6 to 0.9 MeV. $Cesium^{137}$, which emits 0.66 MeV photons, is the dominant gamma emitter among fission products which have cooled more than 3 years. High-level waste has similar radiation properties. There is a low level of neutron emission from spent fuel (less from HLW), but this is not considered to be significant to brine migration. Alpha and beta radiation do not penetrate the waste package.

An available and convenient source of radiation is $cobalt^{60}$. $Cobalt^{60}$ is obtained from neutron activation of cobalt and has a half-life of 5.3 years. Co^{60} produces gamma rays whose energies are 1.17 and 1.33 MeV (and also betas which are not significant here). These energies are somewhat higher than the energies produced by waste forms, but it is considered that Co^{60} will provide an acceptable simulation of the effects of radiation in the salt.

5.4.1 SOURCE STRENGTH DETERMINATION

The Co^{60} source strength required to give an average dose rate of $3X10^8$ rads/year to the salt (Section 4.3.4) over the two year length of the test was estimated to require a source of 9430 Ci per source canister assuming that the source is ordered four months prior to emplacement.

This strength has been established as the design value for transportation container design. The distribution of dose to the salt along the length of the wall will vary somewhat due to the gap in the source from the lifting pintle on the canister. This effect is judged to be acceptable since the majority of the salt is exposed to the desired dose rate.

5.4.2 THERMAL OUTPUT OF SOURCE

The heat output from Co^{60} is 1 kW per 65,000 Ci. Using two 9430 Ci sources per test site yields an initial heat output of 290 watts per site from the radioactive source. From Section 6.2.5, the Asse test sites are estimated to require 2.6 kW to produce the desired temperature. Thus, electrical heating would be required to add the additional heat and to compensate for the decrease in heat produced by the source due to the 5.3 year half-life of the source.

It is noted that the heat released by a Co^{60} source occurs where the gamma rays are absorbed. Most of the gamma rays will be absorbed in the test apparatus, but some will be absorbed in the salt. This will slightly reduce the peak salt temperature and temperature gradient due to the reduced heat flux near the borehole wall. This is judged to be an insignificant perturbation.

5.4.3 Description of Radioactive Sources

Radioactive sources will be required at two of the test locations. There will be two source assemblies in each of these test locations. These source assemblies will be contained in canisters for handling purposes.

The source material will be cobalt^{60} having a strength of 9430 Ci/assembly. A source assembly will consist of five subsources shown on Figure 5-14. Each subsource will be 152 mm (6 in) long and 9.5 mm (0.37 in) in diameter. This subsource will be encapsulate once in a stainless steel tube having an outside diameter of 11.1 mm (0.44 in), and a length of 159 mm (6.25 in). Five of these subsources will be encapsulated in a stainless steel tube with an outside diameter of 13.1 mm (0.52 in) and a total length of 800 mm (33.8 in). Stainless steel spacers 16.25 mm (0.64 in) long will be used between adjacent subsources.

The source assembly will be contained in a source holder, which is a tube with an outside diameter of about 20 mm (0.75 in) and long enough to hold the entire source with a mechanical closure at its top. The source holder is finned so that the source will be centrally located when the source holder is installed into the canister.

The canister will be 1 meter (39.3 in) long, including of the pintle on its top end, and will have an outside diameter of 210 mm (8.26 in). The top of the canister will have a mechanical closure with a pintle to allow for grappling. The bottom of the canister will be indented to center the pintle from a lower canister when the canisters are stacked. There will be two radioactive canister and one shielding canister per radioactive test site. The nonradioactive test sites will include nonradioactive canisters to limit convection.

5.4.4 Handling of Cobalt^{60} Radiation Sources

The problems arising during handling and shipping of the cobalt^{60} sources are not expected to be significantly different from those previously encountered when handling and shipping material of this nature. Regulations governing shipment overland and by sea of this type of material are established by from

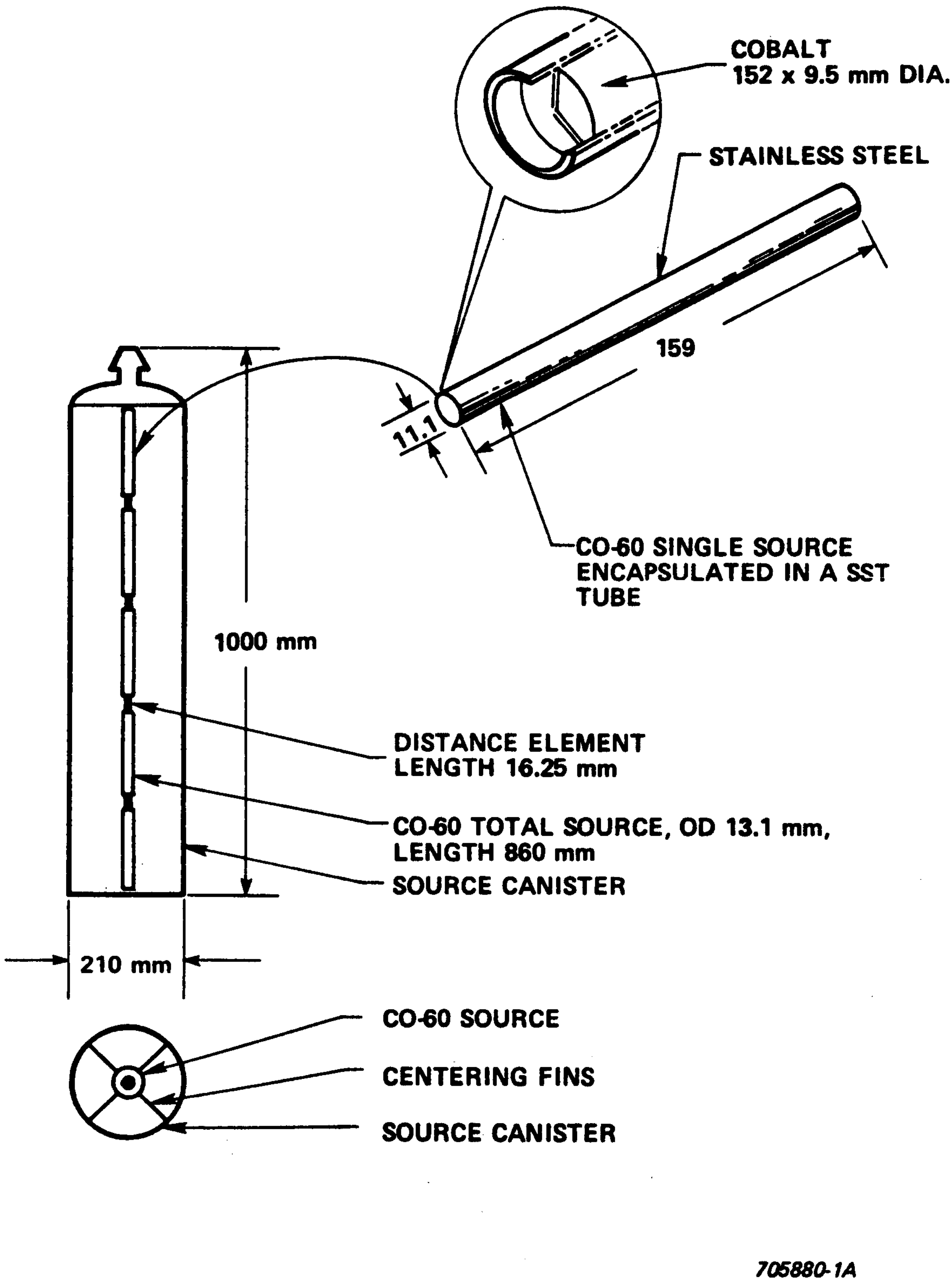

Figure 5-14. Cobalt 60 Radioactive Source Element Double Encapsulated and Inserted Into Source Canister

the International Atomic Energy Agency (IAEA). These regulations will be adhered to during shipment of these sources.

The sources will be double encapsulated and manufactured in the United Kingdom. Canisters will be manufactured in the United States and shipped to the source vendor who will install the sources into the canisters. Each canister will contain source material which will have a strength of 9430 Ci. The source vendor will install the loaded canisters into licensed shipping casks and ship the canisters to the Asse mine hot cell.

All of the above operations regarding source manufacture, source installation into canisters, and subsequent canister installation into shielding casks will be conducted in accordance with established and proven procedures for personnel and environmental protection. Installation of the sources into the canisters and the canisters into the shipping casks will be done remotely in the source vendor's hot cell. The design of the canister will be furnished to the source vendor to ensure compatibility of the source with the canister and also to assure the vendor's capability to handle the canister. A dummy canister will be supplied early to the source vendor to permit the development of procedures for canister operations and also to afford the opportunity for the source vendor to practice prior to the actual operations. Handling of the sources and the loaded canisters will be monitored to assure compliance with proven procedures.

The loaded casks will be shipped to the Asse mine site in the FRG. Here, the canisters will be transferred from the shielding casks into the hot cell at the mine. The cask will have capacity for one canister at a time. Therefore this operation will be repeated for each of the sources. Subsequently, the sources will be reinserted into the shielding cask for transfer underground. The loaded cask will be transported into the mine to the experiment site, where the canister will be installed in the test site. Upon completion of the installation, the cask will be returned to the hot cell to receive the next canister. This cycle of operations will be done four times to complete the transfer of all source canisters from the shipping casks to the test sites. Intermediate operations will use the installation cask to emplace the thermal shield and the shield plug in the experiment sites.

The operations at the Asse mine will be conducted in accordance with procedures which have been reviewed and rehearsed to assure maximum protection to personnel and the environment. The canister design and a dummy canister will be supplied early to Asse so that operating procedures can be developed and practiced.

The shielding cask is being designed and manufactured in the FRG. The cask will be designed to FRG standards which allow a maximum dose rate on contact of 200 mrem/hour, and the maximum dose rate at a distance of 1 meter of 10 mrem/hour.

At the conclusion of the experiment, the canisters will be removed from the individual test sites and returned to the Asse hot cell. The cask used for installation of the canisters will be used for retrieval operations. At the hot cell, the canisters will be removed from the cask and stored pending return to the source vendor who will assume responsibility for the sources. It is anticipated that retrieval operations will be the reverse of the corresponding operations followed during installation.

5.5 SUPPORT FACILITY REQUIREMENTS

There are certain requirements of a physical or material nature that the Support Facility is expected to supply. These will include clean storage and assembly areas, tools, equipment, and services which are needed prior to and during the operational phase of the experiment. The following preliminary list of requirements is to be provided by the support facility:

- Clean storage area
- Clean assembly area
- Standard set of mechanics hand tools (English sized wrenches, etc. as required will be provided by the U. S.)
- Protective clothing (hard hats, gloves, smocks, safety glasses, etc.)
- Individual dosimetry (if required)

- Lubrication (neolube)
- Distilled water
- Clean lint-free rags
- Portable shielding (lead bricks, lead chain, lead shot bags)
- Radiation measurement equipment
- Shop air (100 psig (0.6 MPa) max)
- Services (lighting, electric power, ventilation, communica- tions)
- Cloth backed adhesive tape
- Load indicators
- Nylon rope, (0-1000 lb rating)
- Torque wrenches (0-100 in-lbs (1 kg-m) and 0-100 foot-lbs (15 kg-m))
- Vacuum cleaner
- 3 mil (.01 mm)-thick colored polyethylene sheet
- 24" (0.5 m) steel level
- 6-10 foot (2-3 m) steel tape
- Mallet (rubber, plastic)
- Magnetic retrieval tool
- Eyebolts or any lifting attachments (tested and certified)
- Ohmmeter, voltmeter, ammeter
- Electrical tape
- Standard instrument technician's tool set
- Environmental chamber (if magnetic tape system is located at test site)
- Wood platforms for DAS 3 feet x 2 feet (1 X 0.6 m)
  Wood platforms for remote scanners 2 feet x 2 feet (0.6 X 0.6 m) (five required)
  Wood platforms for power controls 2 feet x 2 feet (0.6 X 0.6 m) (2 for each test site)

Wood platforms for moisture collection system (All wood platforms can use standard wooden building materials)

- Environmental measuring equipment (temperature, radiation)
- Borescope
- Camera (for obtaining photographs of hole interiors and test setup)

5.6 DEVELOPMENT TESTING

As is the case in many experiments which are to be conducted in a hostile environment, there are components which should be tested individually prior to use to ensure they will function as required for the duration of the experiment. Test hardware for the brine migration experiment will be subject to a temperature of up to 350°C, lithostatic pressure of up to 25 MPa (3800 psi), a radiation dose of $6X10^8$ rads ($12X10^8$ inside the sleeve), and a salt-brine atmosphere for a period of two years. Simultaneous imposition of these conditions is severe, and it is concluded that a developmental test program is required for the seal components surrounding the upper sleeve and the porous media surrounding the lower sleeve to confirm material choices and design configurations. Other tests will be conducted to assure adequate assembly and operation of test components.

5.6.1 O-ring Seal Testing

The two-part seal is described in Section 5.2.2.2. One part will be an O-ring configuration of ethylene propylene diene monomer material. The O-rings, four in number and in series, are to provide an effective seal against the brine and gas environment at up to 2 MPa (300 psi) and 130°C (270°F) and with a radiation exposure of $4X10^5$ rads. The purpose of the test is twofold; to determine the optimum seal geometry and seal material characteristics to provide a good initial seal, and to ensure that the seal will continue to perform well after a period of exposure to the expected environmental conditions (except radiation).

The test equipment will consist of a heated and pressurized test vessel which will contain brine. A mockup of the seal geometry will be included in this vessel with provision to adjust the seal tolerances and to measure seal leakage. O-rings are a squeeze-type packing, and the amount of clearance between the closure housing and the O-ring determines whether an effective seal can be achieved. Initial screening tests will be conducted with nitrogen gas pressure and demineralized water at design pressure and temperature conditions to establish optimum O-ring material hardness and clearances. The selected O-ring configuration will then be endurance tested with prototypic brine solution at elevated temperature and pressure. Monitoring of the leakage will be by observing pressure increases in a sampling cylinder external to the pressure vessel. Post testing observations will be made of material elasticity and compression set and moisture absorption.

5.6.2 Castable Seal Testing

The other component of the seal system is the castable seal which is emplaced between the salt borehole wall and the caisson. Several phases of testing will be conducted with this material. First, several different material formulations will be evaluated to determine the best combination of initial viscosity (so the material can be emplaced), shrinkage (so the seal will not pull away from the wall), and adhesion to salt and Inconel. The second phase will test the ability to actually inject the material into the mockup of the seal geometry and achieve an initial high quality seal. Salt will not be used as a borehole wall for this test. Finally, an endurance test will be conducted similarly to that for the O-ring seals described above, exposing the seal to temperature, brine and shear stress conditions.

5.6.3 Porous Medium Testing

The porous medium is described in Section 5.2.2.6. Alumina has been selected as the prime candidate for this application with carbon and graphite as backups. This selection is based on a literature survey of material characteristics which do not include the full range of the experimental conditions. To assure that the materials will perform as required, several tests are being performed.

The beads will be required to support the salt under a compressive load of up to 25 MPa (3800 psi). Since the beads are made of a brittle ceramic material and will be in a random point contact configuration, it is not possible to use standard data to assure sufficient strength to support this load. Therefore, a series of compressive strength tests will be conducted with samples of candidate materials in the desired configuration to determine the breaking strength in practice. These tests will include bead-to-bead bearing tests and tests on collections of beads. Initial screening tests have been promising.

A second required characteristic of the porous media is that it not react with water to a significant extent. For instance, the stable phase of alumina (Al_2O_3) in the presence of water is Gibbsite ($Al_2O_3 \cdot 3H_2O$) or Boehmite ($Al_2O_3 \cdot H_2O$). Formation of these products would tie up water so that it would not be collected by the moisture collection system, although it could be quantified in post-test evaluation. It is expected that the rate of the hydration reaction will be slow enough as not to present difficulties for testing. To assure that this is so, testing will be conducted by exposing candidate materials to a synthetic brine solution and to water vapor at elevated temperature and pressure to observe the amount of water which reacts with or is absorbed by the beads. Following these studies, strength tests will be repeated to assure that there will not be significant loss of strength.

A third test is concerned with the geometry of the borehole gap and the ability to pour the beads into this region. A transparent mockup of this gap will be constructed and various filling techniques such as vibration, tamping, and fluidization will be used to find the best method of filling the gap area with beads. Also, this test may disclose a necessity to modify the equipment geometry somewhat to eliminate volumes that cannot be filled.

5.6.4 Instrumentation Testing

Tests will be conducted concerning instrumentation. One test will be to verify the method of installing thermocouples against the salt borehole wall. This test will be conducted using the same transparent borehole mockup as used for the media pouring tests described above.

A test has been conducted to verify that state-of-the-art data acquisition systems can adequately reject electrical noise. The potential problem is that a large amount of electrical noise will be generated by the SCR controlled power supplies for the electrical heaters used in the test. Much of this noise will coupled to the low level instrumentation lines and this noise must be rejected by the data acquisition system. To conduct this test, available equipment was assembled to simulate the electrical noise environment, including an SCR power supply, heater, and typical instrumentation inputs. A representative data acquisition system having good noise rejection specifications was lent by a vendor for this test. The result was that no detectable degradation of the accuracy of measured parameters was noted. This indicates that the approach is feasible. The final equipment will be confirmed for noise rejection adequacy before shipping to Germany.

A test will be conducted to assure that the method of protecting the strain gauges on the lower sleeve from local damage from the beads will not affect the strain gauge output. This will involve a mockup of a section of sleeve with strain gauge and cover being placed in a materials testing machine to develop surface loads. Influence of these loads on the gauge output will be recorded.

5.7 TEST ASSEMBLY CHECKOUT

Prior to shipping to the test site, a number of operational and functional tests will be performed on each test assembly. These tests include:

- Sleeve leak test
- O-ring leak test
- System functional test

The sleeve leak test will verify that the experiment sleeve and its penetration seals properly fit up and will limit leakage to the sleeve region.

With the sleeve inserted in the caisson, the lower two O-ring seals will be checked by injecting gas into the pressure balancing port between the lower two O-rings.

A final system functional test will also be performed on the test assembly (including guard heaters). The power controllers will be integrated with the assembly tubular heaters and checked out. The data acquisition and moisture collection systems will also be integrated with the test assembly, and a functional test of these systems performed.

6.0 EXPERIMENT ANALYSIS MODEL DESCRIPTION AND RESULTS

Section 6 presents the description of the calculations being performed which are being used as a basis for brine migration test development and a summary of the results available at this time. These models include thermal analysis, brine migration analysis by liquid inclusion and by vapor migration, radiation shielding calculations, and a salt stress analysis. Also presented are some of the results and conclusions drawn from these results.

6.1 THERMAL ANALYSIS MODELING

Thermal analysis models are provided on two levels:

- An analytical model to describe basic trends and relationships
- A finite difference calculation to obtain a closer estimate of the expected temperature distribution.

6.1.1 Thermal Properties

Conductivity

The thermal conductivity of halite is higher than most other rocks. Thus, impure halite is found to have a lower conductivity than pure halite. The conductivity of pure halite is usually used for analysis because tests and repositories are likely to be located in relatively pure material. The thermal conductivity of halite is temperature dependent, decreasing at higher temperatures. It approximately follows the law that, for dielectrics, the conductivity is proportional to the inverse of the absolute temperature (above very low temperatures). The most widely used conductivity values in the U.S. are those of Birch and Clark for halite (1940).

BGR* has measured the conductivity of Asse salt and finds that it matches the Birch and Clark values above 100°C and is about 5 percent lower at ambient temperature (Schmidt, 1971). Table 6-1 presents these values.

*Bundesanstalt für Geowissenschaften und Rohstoffe (BGR)

TABLE 6-1

HALITE CONDUCTIVITY VALUES

Temperature - °C	Conductivity - W/m-°C	
	Birch and Clark	IfT
0	6.10	5.73
50	5.01	4.88
100	4.20	4.17
150	3.60	3.57
200	3.11	3.08
250	2.77	2.69

IfT and KFK* have also measured volumetric heat capacity of Asse halite and developed the relation (Kopietz and Jung, 1978),

$$\rho C_p = 1.87049 \times 10^6 + 1.9386 \times 10^2 \; T$$

where,

ρC_p is volumetric heat capacity in J/m^3 -°C
T is temperature in °C

6.1.2 Analytical Temperature Calculations

An analytical expression has been developed to describe the steady-state temperature field around a finite length line heat source in a uniform infinite medium. The expression was developed by integrating the steady state solution for a point source along a line.

The constant conductivity assumption is not valid for salt, but by selecting an appropriate average conductivity, useful results can be obtained. Another simplification is neglecting that the experimental source has a finite diameter,

*Kernforshungszentrun Karlsruhe (KFK)

about one-fifth of the length. This will only affect the solution near the ends of the source. The distribution of heat from the radioactive source has been neglected. The effect of the mine drift has not been incluaed. The expression is:

$$T - T_\infty = \frac{Q}{8\pi k \ell} \ell n \left[\frac{(Zo-1) - \sqrt{(Zo-1)^2 + Xo^2}}{(Zo+1) - \sqrt{(Zo+1)^2 + Xo^2}} \right] \qquad 6.1\text{-}1$$

where,

- T = Temperature at (Xo, Zo) - °C
- T_∞ = Initial or background temperature - °C
- Q = Total source heat output - watts
- k = Conductivity of medium - W/m-°C
- ℓ = Half length of source - m
- Zo = Reduced axial distance from axial source centerline, ratio of actual distance to ℓ - dimensionless
- Xo = Reduced radial distance from source centerline, ratio of actual distance to ℓ - dimensionless
- ℓn = Natural log

For Zo = 0, this reduces to:

$$T - T_\infty = \frac{Q}{8\pi k \ell} \ell n \left[\frac{-1 - \sqrt{1 + Xo^2}}{1 - \sqrt{1 + Xo^2}} \right] \qquad 6.1\text{-}2$$

The gradient of temperature with respect to Xo at Zo = 0 is:

$$\frac{dT}{dXo} = \frac{-Q}{4\pi k \ell} \frac{1}{Xo\sqrt{1 + Xo^2}} \qquad 6.1\text{-}3$$

From these equations, the following curves have been prepared:

Figure 6-1. This graph shows dimensionless isotherms around the source.

Figure 6-2. This graph shows dimensionless temperature profiles along the Xo axis for different values of Zo.

Figure 6-3. This graph shows the dimensionless gradient of temperature with respect to Xo at Zo = 0.

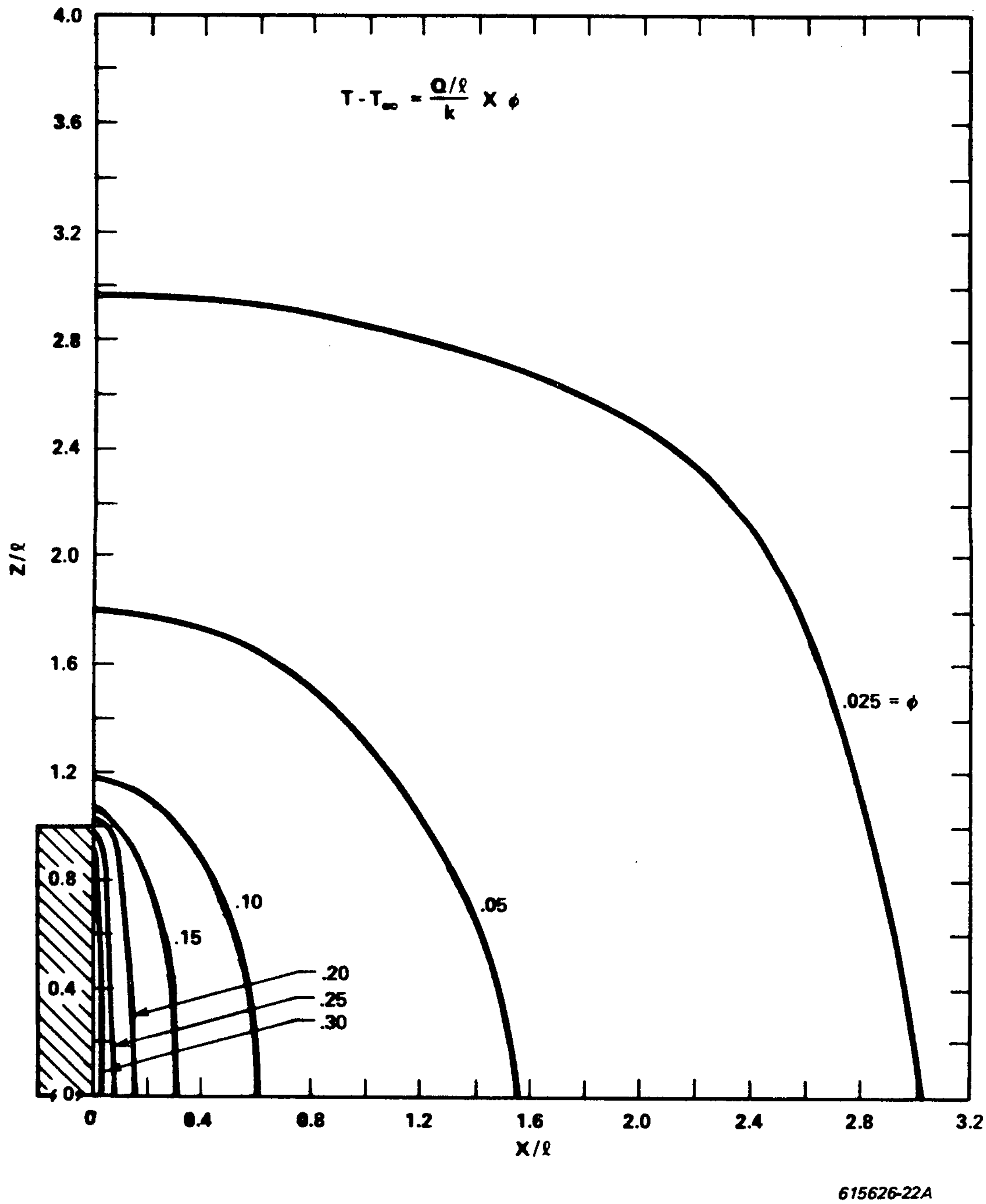

Figure 6-1. Universal Temperature Profile Around a Finite Length Line Source

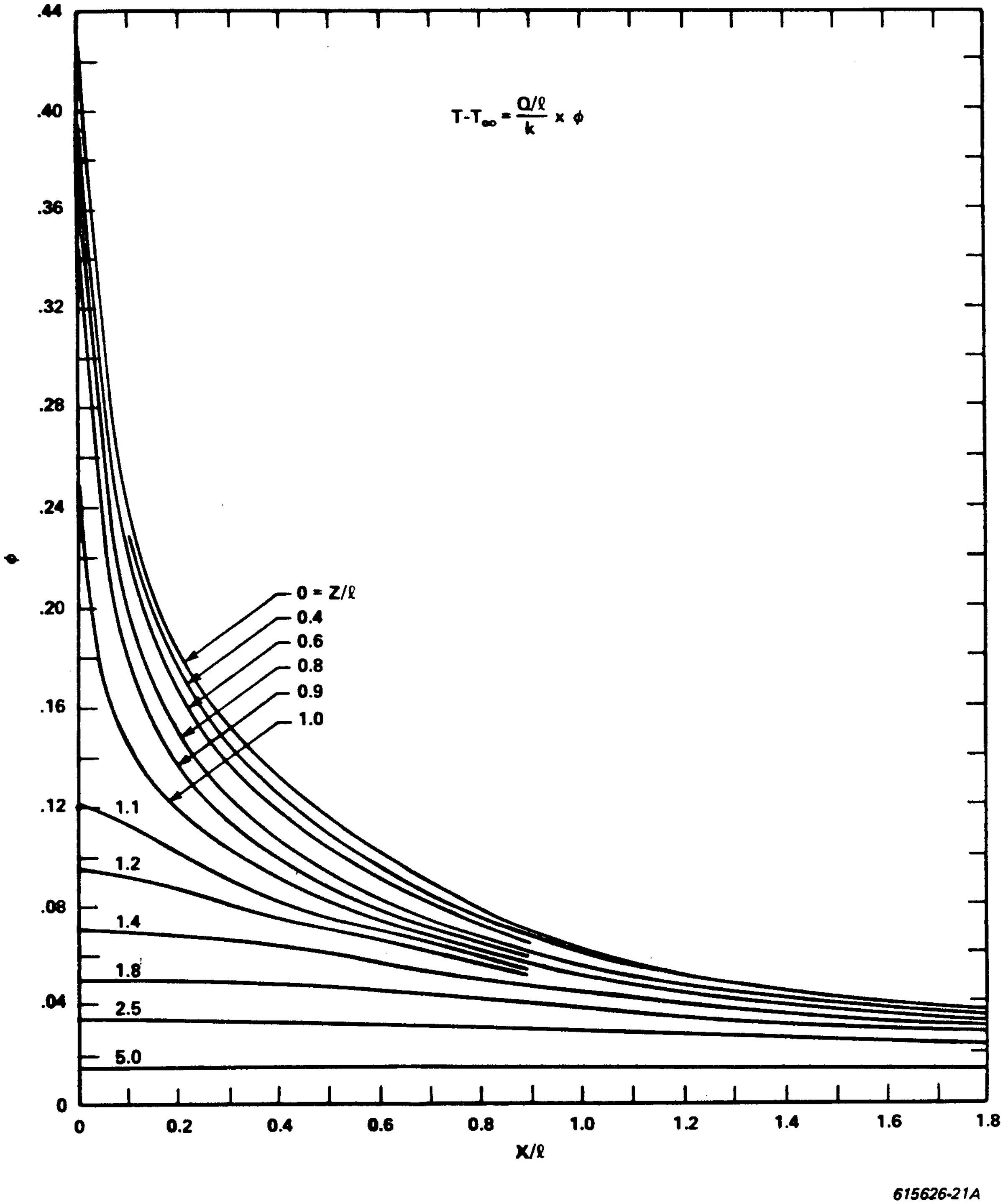

Figure 6-2. Dimensionless Temperature Profiles Parallel to X-Axis Around a Finite Length Line Source

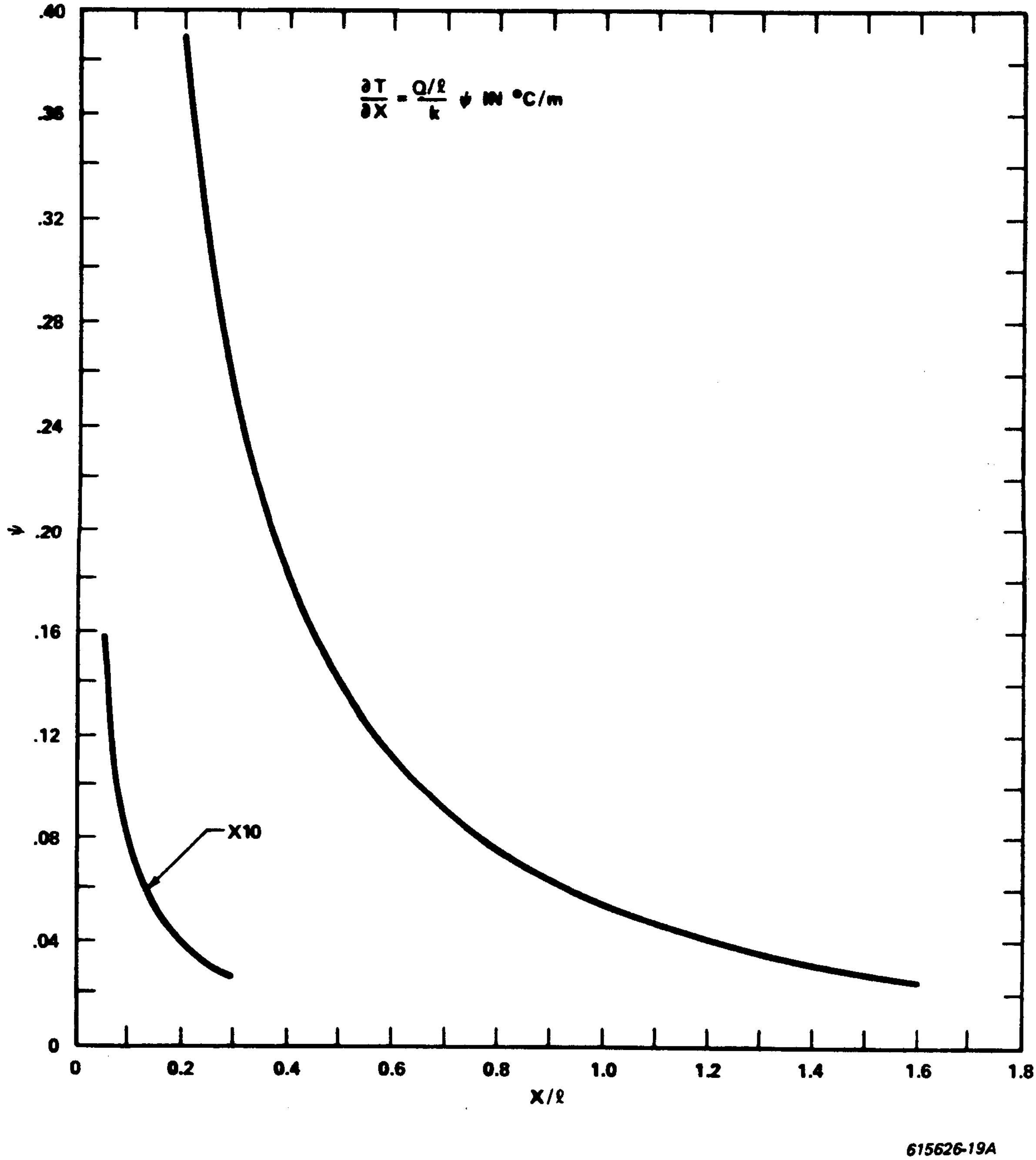

Figure 6-3. Dimensionless Temperature Gradient on the X-Axis Around a Finite Length Line Source

It is recommended that for temperature level calculations, a conductivity value representing the average of the ambient and local temperature be used for this formula. For temperature gradient calculations, use of the conductivity at the local temperature is more realistic.

6.1.3 Finite Difference Temperature Calculations

To develop a more accurate analysis of the temperature field around the experiment, including the actual site of the experimental apparatus, the effect of the mine opening above the test, the variable thermal conductivity, and to obtain transient response data, a finite difference temperature model of the test was developed. The Westinghouse computer program, TAP-A (1970), was used for these calculations. This model was developed to provide a calculation of the temperature distribution in the salt around the experiment and also to provide an estimate of the maximum temperature at the seal. The interior of the sleeve was not modeled explicitly. The guard heaters were modeled as a ring at the appropriate radius. The boundaries were each fixed at the ambient temperature and were located at a sufficient distance (50 meters) so as not to influence the solution except for the upper boundary, which represents the mine opening. Figures 6-4 and 6-5 show the calculational mesh used for this analysis. The variable salt conductivity of Birch and Clark, Table 6-1, is used in this calculation.

6.2 THERMAL RESULTS AND CONCLUSIONS

6.2.1 Experiment Heated Length

Design considerations (Section 5.2) have established an experiment borehole diameter of 43.5 cm. The heated length of the experiment is determined by the desire to have a relatively uniform temperature profile over most of the heated length. From Figure 6-1, it can be seen that this condition is satisfied for a radius up to about Xo = 0.2. This corresponds to an overall heated length of 2.17 meters. Hardware design considerations require a slightly shorter length than this, but axial conductivity of the sleeve acts to help flatten the temperature distribution. The distribution shown in Section 6.2.4 is judged to be acceptable.

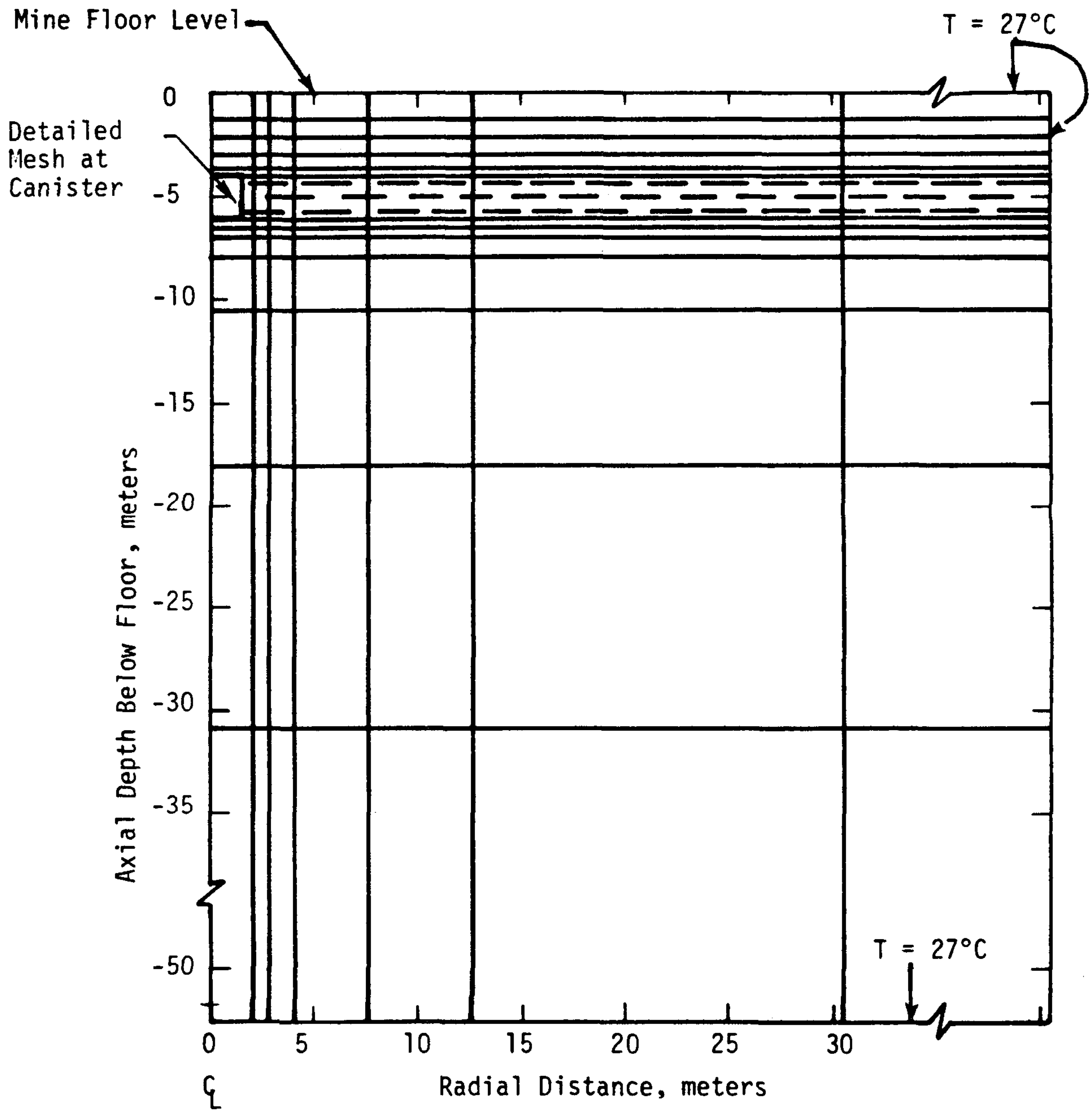

Figure 6-4. Axisymmetric Model for Thermal Analysis of Brine Migration Test

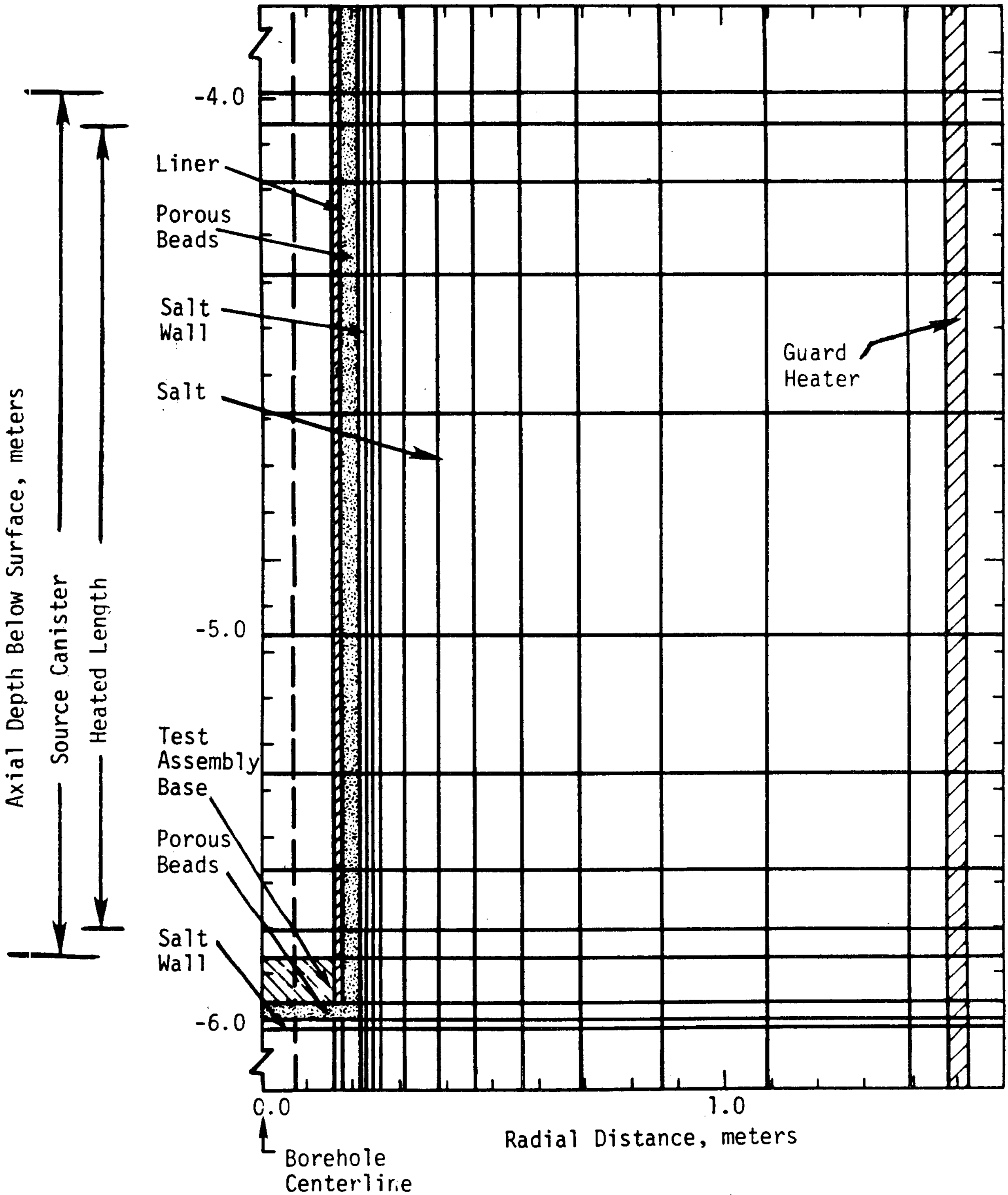

Figure 6-5. Detail of Central Region of Axisymmetric Model for Thermal Analysis of Brine Migration Test

6.2.2 Approximate Central and Guard Heater Power Requirements

Power Levels

It is desired to have a borehole wall temperature of 210°C and temperature gradient of approximately 3°C/cm. From Figure 6-3, the heat required of the central heater to produce the desired temperature gradient is determined. The borehole radius is 21.75 cm and the heater half length is 88 cm so Xo = 0.25. Using this valve, ψ is found to be 0.308. Using the conductivity of salt at 210°C of 3.0 W/m-°C from Table 6-1, the required central heater power is found to be:

$$\frac{\partial T}{\partial X} = \frac{Q_{ch}/\ell}{k}\psi$$

$$Q_{ch} = \frac{\partial T}{\partial X}\frac{k\ \ell}{\psi} = \frac{300\frac{°C}{m} \times 3.0\frac{W}{m-°C} \times 0.88\ m}{0.308}$$

$$Q_{ch} = 2571 \text{ Watts - central heater}$$

Then using Figure 6-2 to find the borehole wall temperature due to the central heater with Xo = 0.25, Zo = 0, Φ is found to be 0.167. The temperature is then, using an average k = 4.5 W/m-°C,

$$T - T_\infty = \frac{Q_{ch}/\ell}{k}\Phi$$

$$T = T_\infty + \frac{Q_{ch}/\ell}{k}\Phi = 27°C + \frac{2571 \text{ Watts}}{0.88\ m} \times \frac{0.167}{4.5\ W/m-°C}$$

$$T = 135°C$$

Since the desired temperature is 210°C, the guard heaters must contribute an additional 210 - 135 = 75°C temperature rise. The guard heaters are 3.5 m long (ℓ = 1.75 m) and they are located at a radius of 1.5 m, so Xo = 1.5 m/1.75 m = 0.85. From Figure 6-2, Φ = 0.0796. Then for the guard heaters,

$$Q_{gh} = \frac{(T - T_\infty)}{\Phi}k\ell = \frac{75°C \times 4.5\ W/m-°C \times 1.75\ m}{0.0796}$$

$$Q_{gh} = 7415 \text{ Watts}$$

These values of 2571 watts for the central heater and 7415 watts for the guard heaters provide preliminary estimates of the power requirements of the heaters. The results demonstrate that the power requirements are reasonable and were used for initial design of the experiment. Further analysis using a more detailed finite difference model will provide more accurate estimates of power levels and temperatures. These are described in Section 6.4.

6.2.3 Number of Guard Heaters

A continuous guard heater ring will produce a uniform temperature inside the ring except near the ends of the ring. When the continuous ring is broken into discrete heaters, the temperature inside the ring becomes nonuniform, with small variations at the center of the ring and larger variations near the heaters. For this experiment, it is desired to have a uniform temperature field produced by the guard heaters from the 0.2175 m borehole radius to at least the greatest radius where significant brine migration effects are expected, at about a 1.0 m radius. To provide a margin beyond this radius, the guard heaters are established at a 1.5 meter radius. Since the total guard heater power is high, a number of heaters is required to reduce the local temperature elevation around each guard heater. Using the equations of Section 6.1.2 and the power levels of Section 6.2.2, it was found that eight heaters would be required to limit the local salt temperature elevation around each guard heater to about 45°C. The temperature distribution resulting from 8 heaters in the ring was calculated by using the analytical equations of Section 6.1.2 and superimposing the effects at each point. Figure 6.6 shows the amount of temperature variation that would result with only guard heaters operating. The guard heaters give a very low negative gradient (-0.05°C/cm) around the borehole and little asymmetry (< 0.5°C) within the one meter radius where effects of brine migration are expected to occur. Therefore, the test will incorporate 8 guard heaters.

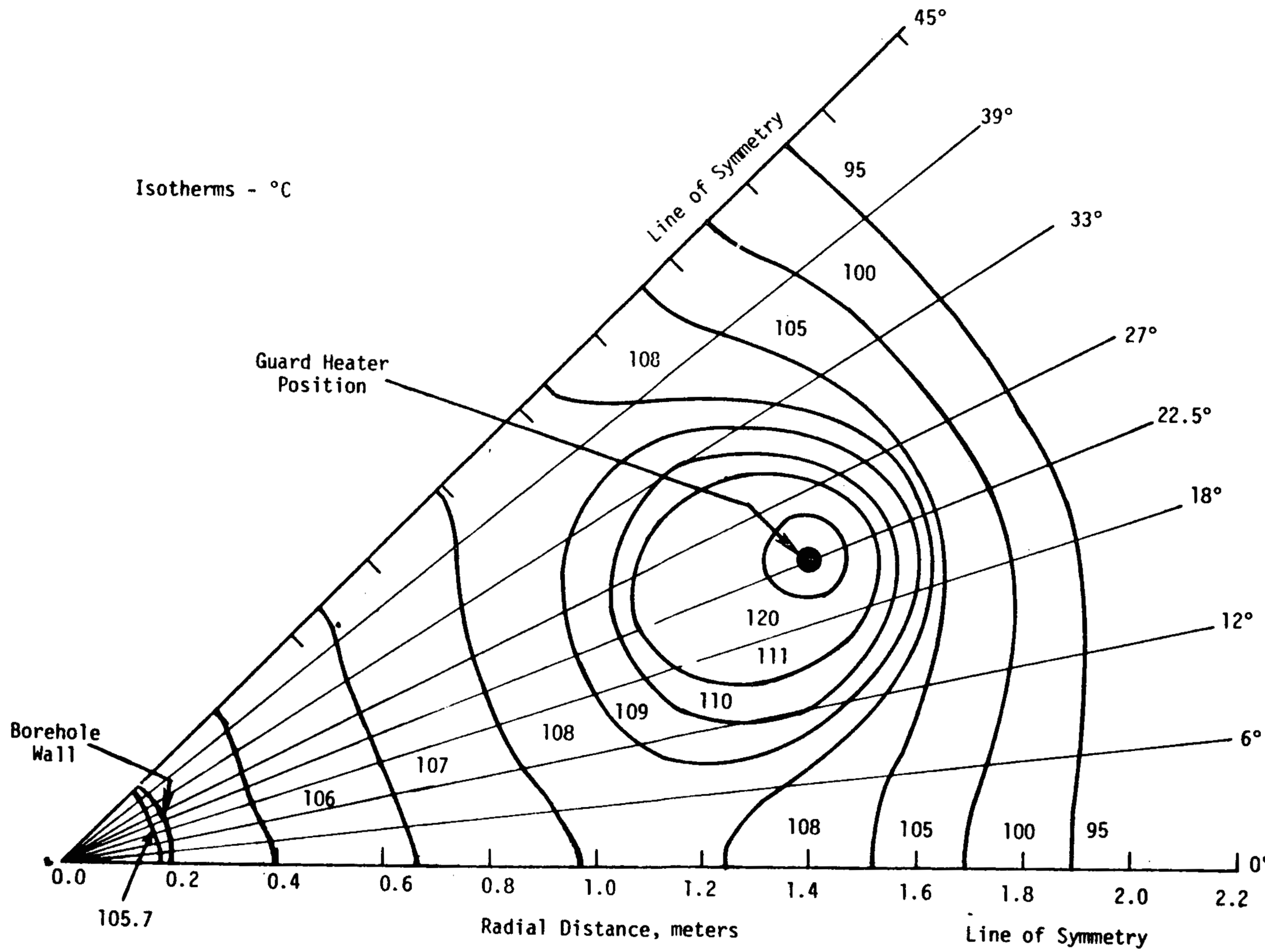

Figure 6-6. Calculated Temperatures Resulting From Guard Heater Operation Only

6.2.4 Detailed Temperature Distributions

Temperature distributions around the experiment were calculated using the detailed finite difference model. The model was used first to produce the desired steady-state temperatures around the test site. The heater power levels were adjusted to obtain the desired borehole wall conditions of 210°C maximum and approximately 3°C/cm gradient. The resulting power levels are 2.42 kW for the central heater and 7.86 kW total heat output of the guard heaters.

These power levels were then used to develop a temperature transient for the two years test duration during which time the temperature essentially reached steady state.

Figure 6-7 shows the temperature profile that resulted from the analysis at the end of the two year transient. The power level is slightly high so the peak salt temperature calculated is 214°C and the peak temperature gradient in the salt is 3.2°C/cm. Figure 6-8 shows the temperature distribution radially outward from the heater midline at various times showing that the heatup transient is nearly complete after 6 months. The temperature gradient at the same location is shown in Figure 6-9 which illustrates the rapid fall-off of gradient with distance into the salt. This fall-off, combined with the temperature decrease, results in the rapid decrease in liquid inclusion migration velocity shown in Section 6.4.

The axial distribution of salt temperature along the salt borehole wall is shown in Figure 6-10. This is a reasonably flat distribution over the center of the irradiated length. Note that the temperature at the seal region is reduced to about 90°C which significantly reduces the thermal damage to the organic seal components. The bottom of the borehole will have a minimum temperature of about 115°C. The axial distribution of radial temperature gradient is shown as Figure 6-11 and shows that a substantial gradient is provided over much of the heated length. Finally, the axial distribution of temperature along the metal sleeve of the test assembly is shown in Figure 6-12. The sleeve temperature peaks at 350°C (670°F) but decreases rapidly beyond the

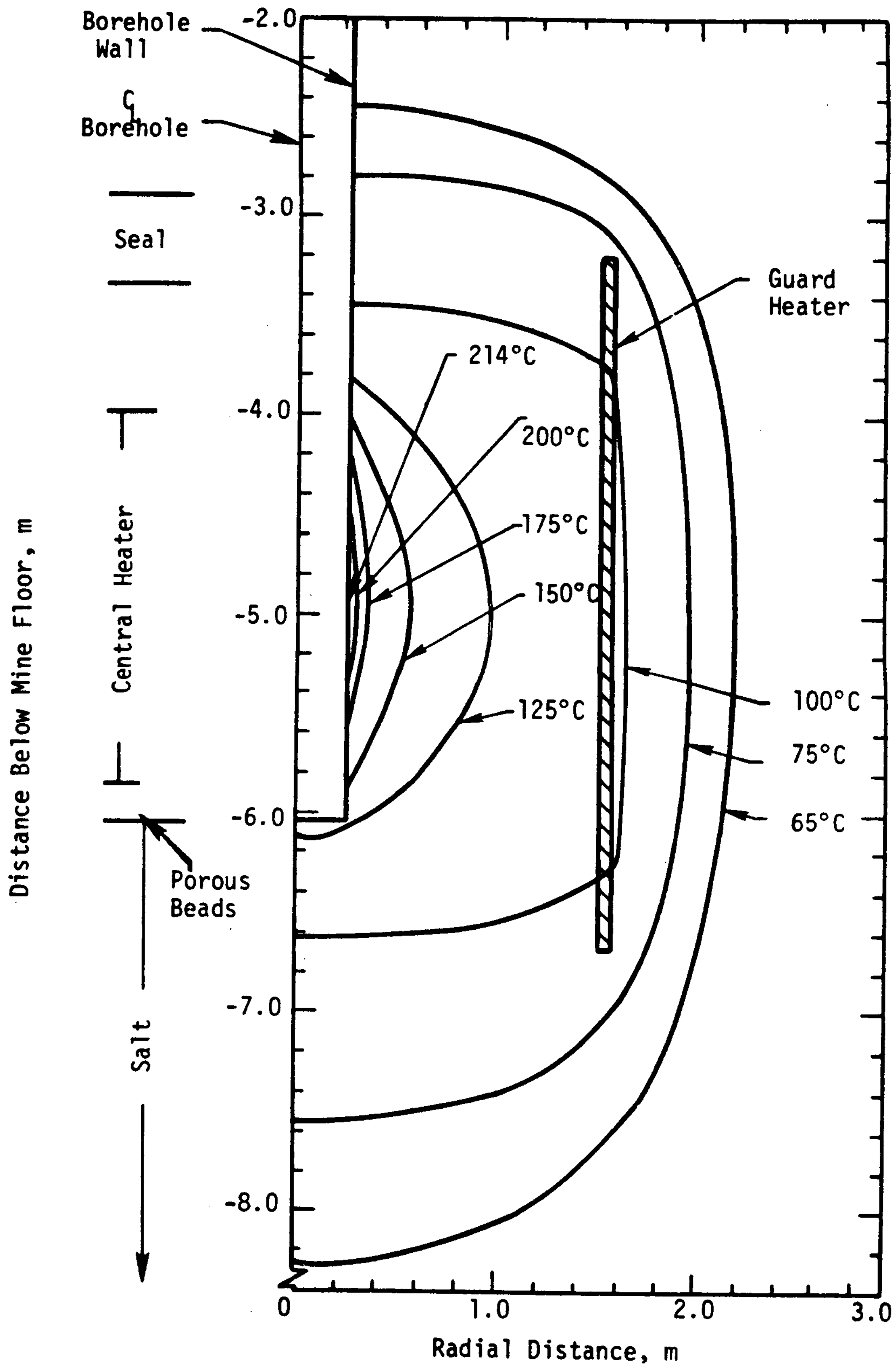

Figure 6-7. Temperature Isotherms Around Brine Migration Test Assembly After Two Years of Heating

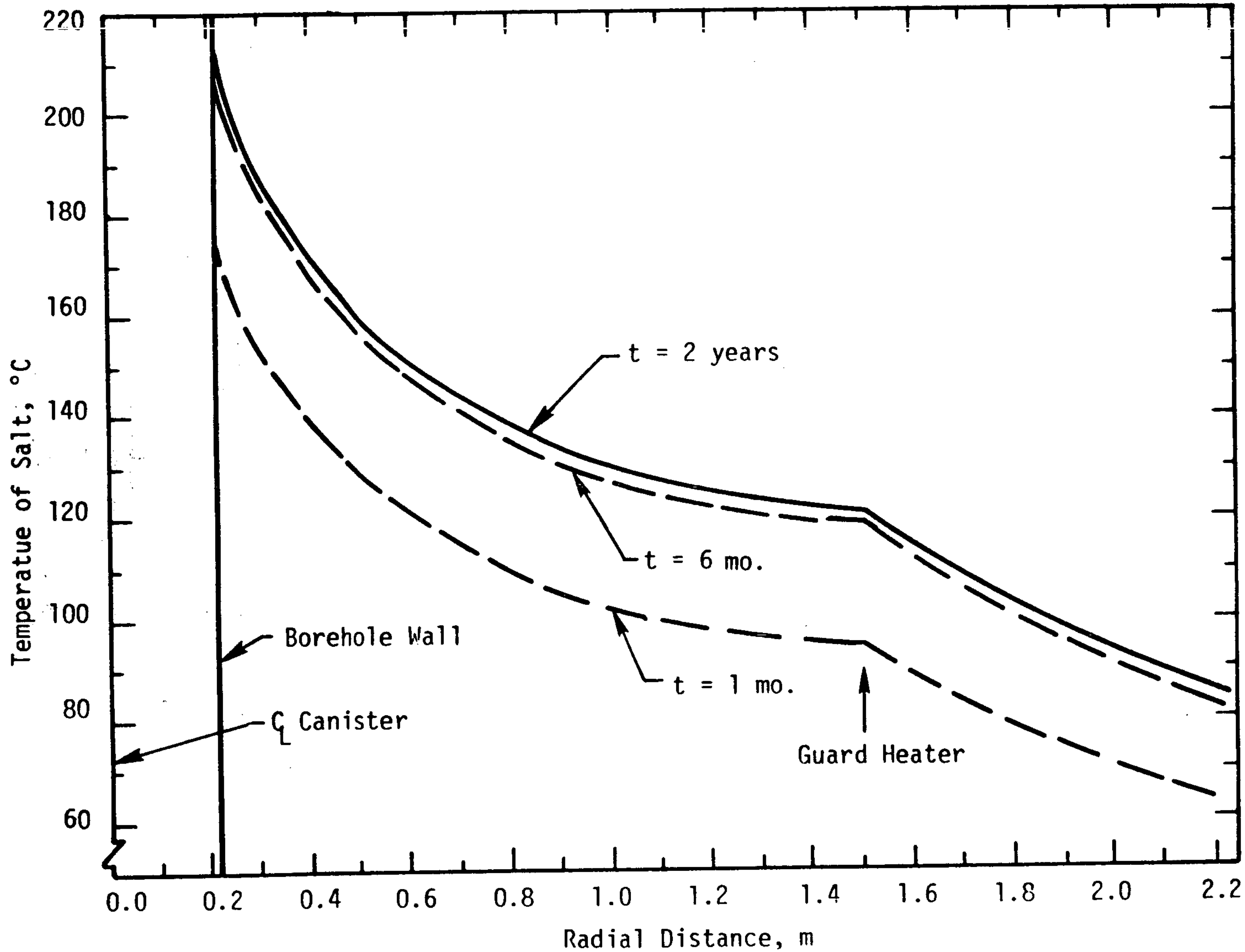

Figure 6-8. Radial Temperature Distribution Around Brine Migration Test Assembly at Heater Midline

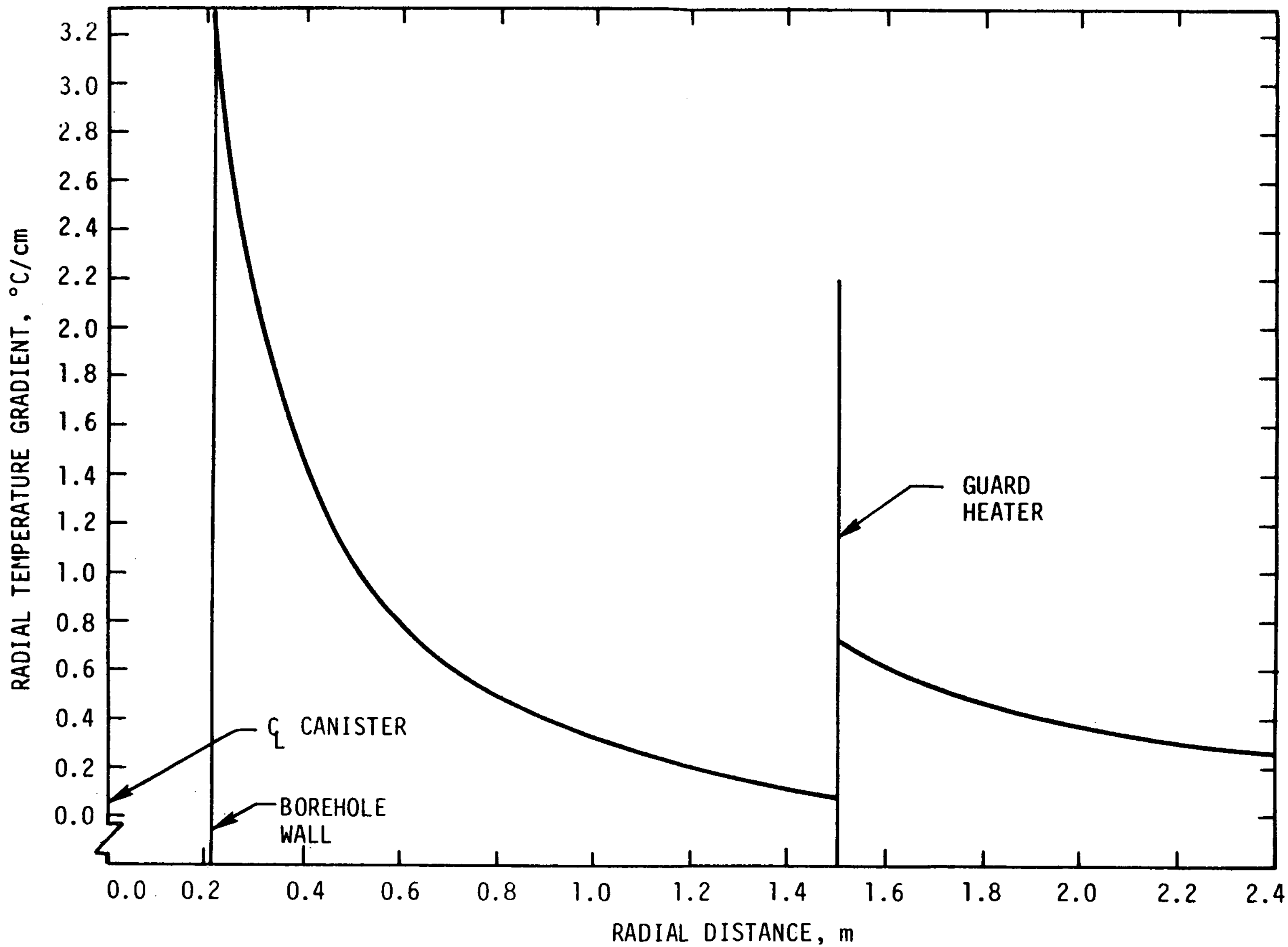

Figure 6-9. Radial Temperature Gradient Around Brine Migration Test Assembly at Heater Midline After Two Years of Heating

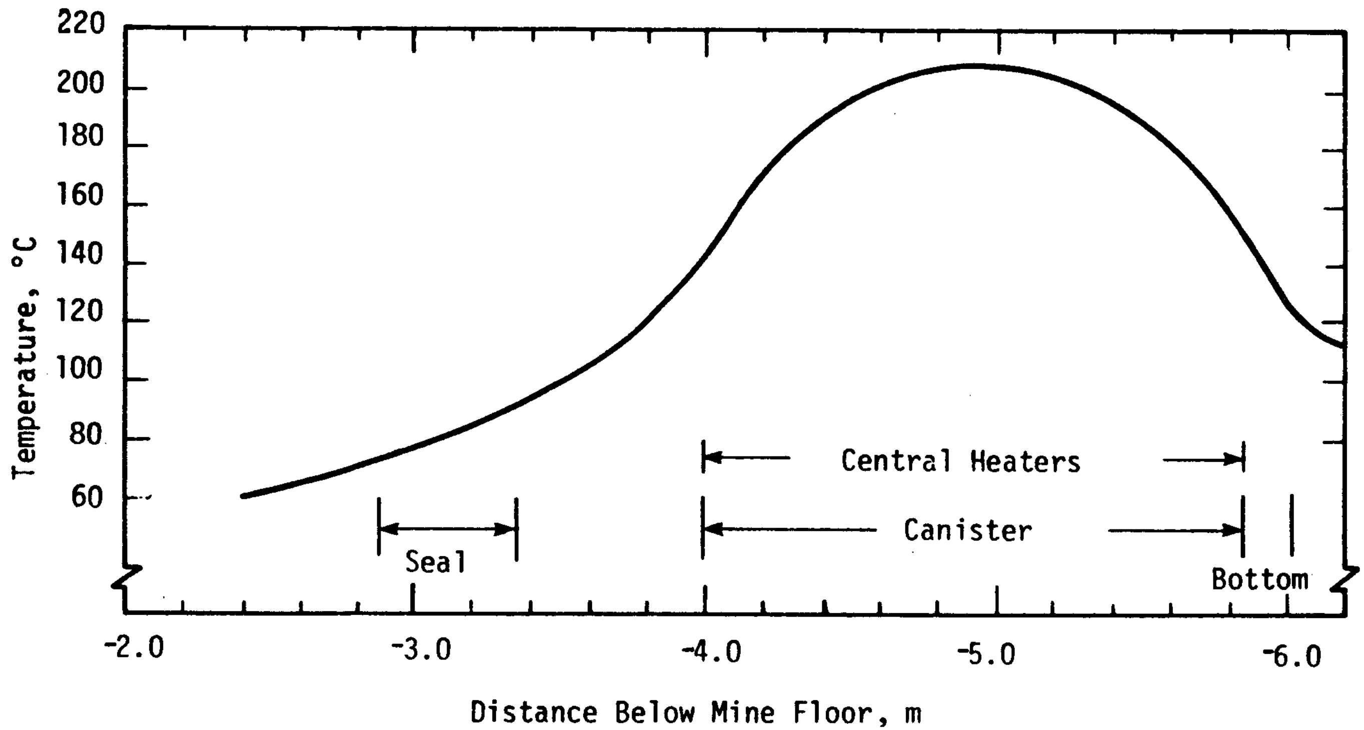

Figure 6-10. Salt Borehole Wall Temperature After Two Years Heating

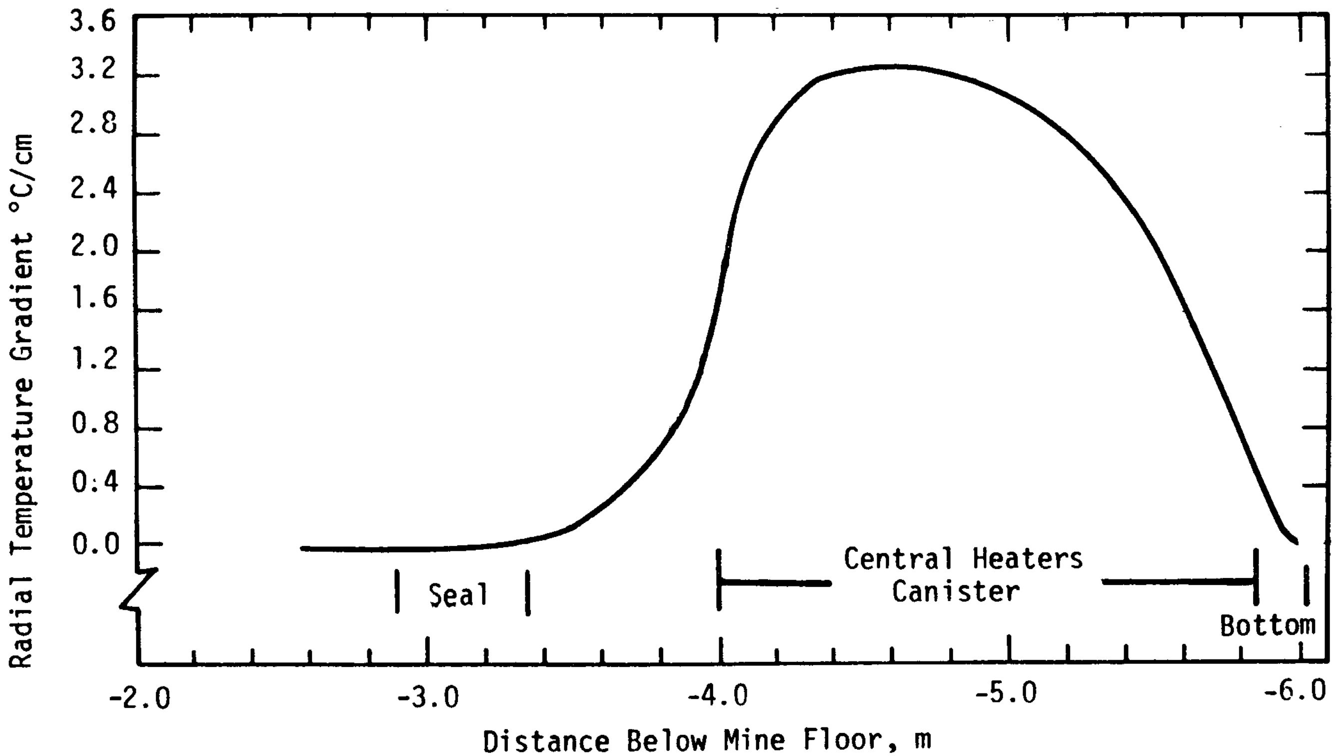

Figure 6-11. Radial Temperature Gradient Along Salt Borehole Wall After Two Years Heating

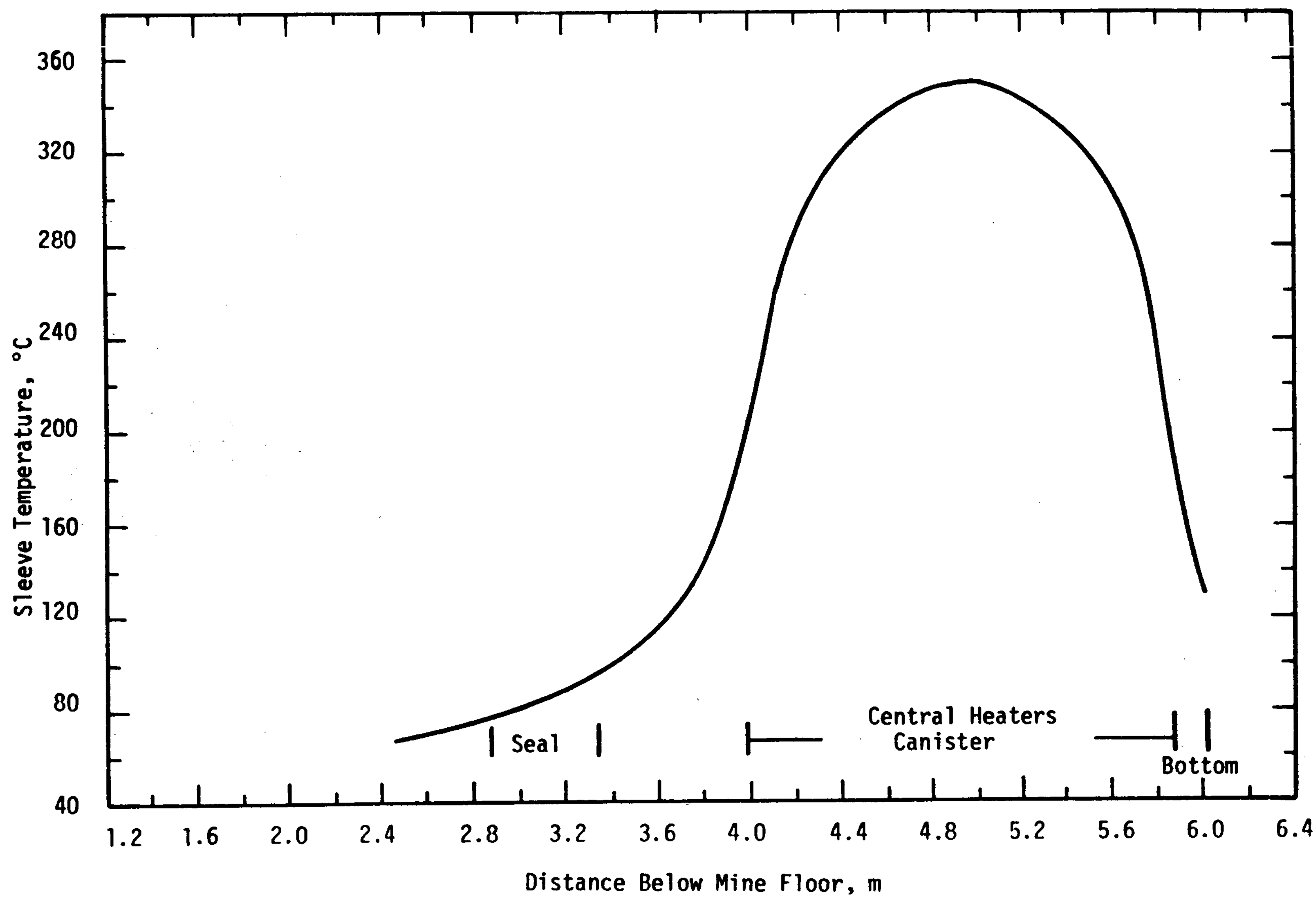

Figure 6-12. Temperature of Test Assembly Sleeve After Two Years Heating

heated region. Other calculations have estimated that the heater rods will operate between 540 and 600°C (1000 and 1100°F), but other components within the sleeve will remain within a few degrees of the sleeve temperature.

6.2.5 REQUIRED TEST SITE SEPARATION (THERMALLY)

The spacing between test sites must be great enough to eliminate interactive effects of the temperature fields. Of interest are the increase of temperature at one site due to heat produced at another and any asymmetric temperature gradient. The spacing of 15 meters has been determined to reduce these two effects to reasonable levels.

The finite difference model is used to estimate the temperature rise at one site due to heat produced at another site. The heat used is the total of the central heater and guard heaters, this is about 10 kW per test site. At a distance of 15 meters, the temperature rise calculated by the finite difference model is 3°C after two years of operation. (This is somewhat less than the steady state temperature rise at 15 meters, but is acceptable for this operation.) It is judged that this much temperature increase is acceptable. The temperature gradient calculated by equation 6.1-3 would be 0.0065°C/cm which is very low. Thus, it is judged that a spacing between test sites of 15 meters, center-to-center, is acceptable.

6.3 LIQUID BRINE INCLUSION MIGRATION MODELING

One of the forms in which water exists in salt is liquid brine inclusions. These inclusions are small pockets of water containing NaCl and other salts in solution either within the salt crystals or on the grain boundaries. It has been observed by many investigators (Jenks, 1979; and RE/SPEC's draft state-of-the-art review of brine migration studies in salt) that the inclusions will move toward a heat source (up a thermal gradient). This migration of liquid has been estimated to release about 10 liters of water (RRC-IWG, 1983) around a waste container over about 100 years after emplacement.

Although there have been several studies of inclusion motion within crystals of salt, little is known about what happens when an inclusion reaches a grain boundary. The water could be trapped at the boundary, it could enter the next crystal and continue to migrate, it could travel along the boundary following the same general mechanism as within the crystal, or it could evaporate and travel as water vapor through small spaces between crystals. In the following, it will be assumed that inclusion motion is not affected by grain boundaries, and relationships developed for motion in individual crystals will be applied to bulk salt. This is the best available information and should be satisfactory to provide a basis for experiment design.

Several theories have been developed to describe liquid inclusion motion in salt, and several tests have been conducted measuring this motion. In most cases, the velocity of motion is concluded to be proportional to the local temperature gradient. The velocity is also increased at higher temperatures. Since the data have exhibited a large degree of variability (even differences of a factor of 4 in velocity of a single inclusion at different points along its path), a commonly used correlation by Jenks (1979) will be used for this study. This correlation gives an estimate of inclusion velocity which includes the larger of the available data points and, thus, provides a high estimate of the amount of water collected in the experiment. Jenk's relationship is:

$$\log V/G = 0.00656T - 0.6036 \qquad 6.3\text{-}1$$

where:

V/G = velocity per unit temperature gradient
T = temperature of salt, °C
V = velocity of inclusion - m/yr
G = temperature gradient - °C/m

In addition to the assumption of negligible grain boundary effect, the above equation also neglects the kinetic potential associated with transferring ions between the liquid and solid phases and the effect of liquid droplet size. In other words, the salt is assumed to contain brine inclusions having size in the range of 2-10 mm, and only brine migration through salt crystals are considered.

The continuity equation applied to the density migration is:

$$\frac{\partial \rho}{\partial t} = \nabla \cdot \rho \vec{V} \qquad 6.3\text{-}2$$

where

ρ = water content per unit volume of the salt - g/cm^3
V = inclusion velocity - m/yr

The thermal analysis from the previous section is used to define the temperatures and temperature gradients for the solution, since for the very low water contents in salt (<0.001 weight fraction), the water motion and temperature solutions are uncoupled.

The liquid inclusion motion equations are solved using the MIGRAIN computer code developed by Scientific Applications, Inc. (SAI) under a separate ONWI contract (Rickertsen, 1980). Westinghouse has independently verified the applicability of the computer program in solving these equations. There is one item of application of this program that requires attention. The temperature gradient is determined from input temperature distributions by numerical differencing of adjacent temperature nodes. At the borehole boundary, it is important to define a salt node point just on the borehole side of the boundary to avoid a spurious temperature gradient calculation at the boundary which could result in an erroneous brine arrival rate from the adjacent node to the borehole boundary. This problem was evident in early unpublished brine concentration profiles developed by SAI.

As applied at Westinghouse, temperature distributions were calculated using the models described in Section 6.2. These were then used as input for MIGRAIN which then calculated liquid inclusion migration results.

6.4 LIQUID INCLUSION BRINE MIGRATION RESULTS

The expected liquid inclusion migration behavior for the test at Asse was calculated using the methods described in Section 6.3. The temperature distribution used was for the design case of 210°C borehole wall temperature and a 3°C/cm maximum thermal gradient as described in Section 6.2. It was assumed that the salt at Asse initially contains 0.05% by weight of water as liquid inclusions. (It is noted that current information indicates that there is very little liquid water in the Asse salt. This calculation is intended to evaluate the behavior assumming liquid water is present in order to judge the adequacy of the experiment design.) Figure 6-13 shows the calculated water arrival rate at the borehole. This is the total water arriving over the entire test annulus and includes the end effect and the transient temperature distribution during experiment heat-up. This curve has two significant features. First, the total amount of water arriving at the test volume is only about 0.38 liters in the two-year test period. This is largely due to assuming only 0.05 wt % water in the salt, a very low value. The water arrival would be directly proportional to water content of the salt. This volume of water is about the amount calculated to raise the vapor pressure in the borehole volume to the saturation pressure of pure water if retained in the hole, so liquid water may not exist. The second feature is that the rate of inflow does not decrease strongly over the test period.

Figure 6-14 shows the calculated brine inclusion velocity as a function of radius at the horizontal centerline of the test section two years into the test when the temperature profile is fully developed. The combined effects of the decreasing temperature and temperature gradient cause the velocity to decrease rapidly with radius from 0.20 m/yr at the borehole wall to 0.045 m/yr 0.20 meters beyond the wall.

Figure 6-15 shows the moisture content of the salt along the horizontal centerline of the test section at several times in the test. The moisture is progressively depleted near the borehole wall over the duration of the test. The depletion at the borehole wall leads directly to the change in inflow rate after the first few months when the temperature field is established.

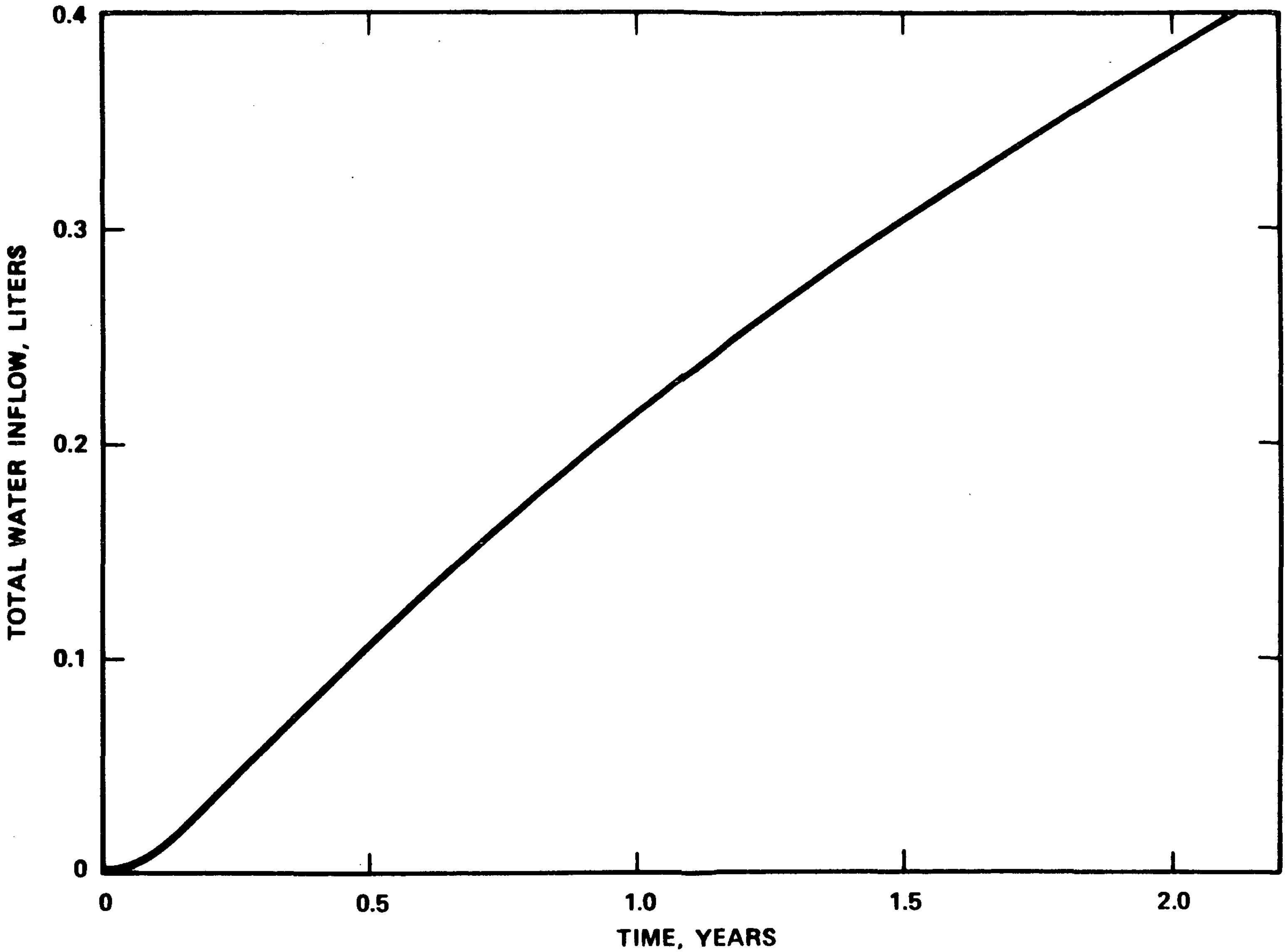

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Figure 6-13. Liquid Brine Inclusion Model Water Production Calculated Based on Assumed 0.05 Wt% Liquid Water in Salt

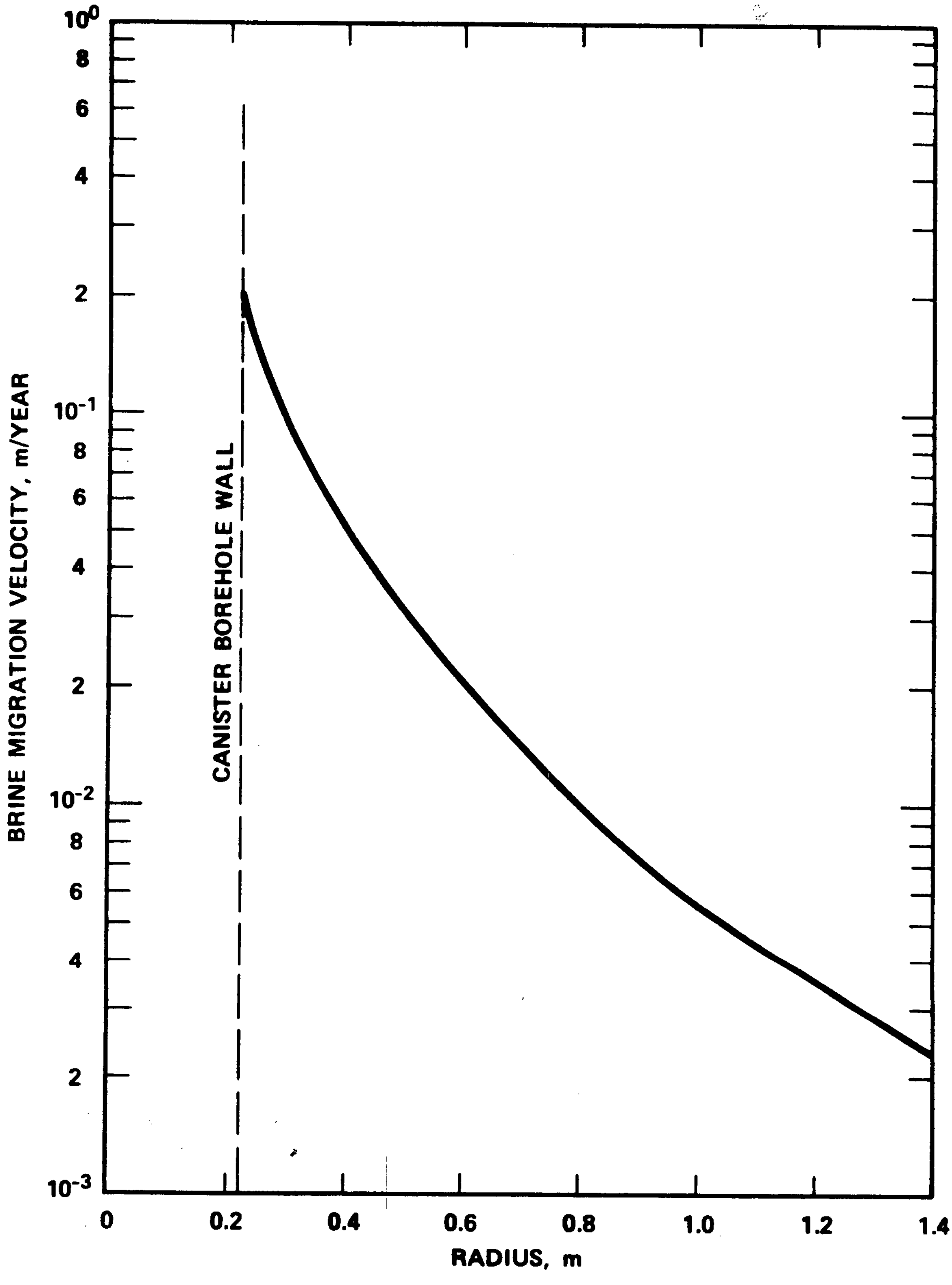

Figure 6-14. Liquid Inclusion Migration, Calculated Inclusion Velocity Along Radial Centerline of Heater After Two Years Heating

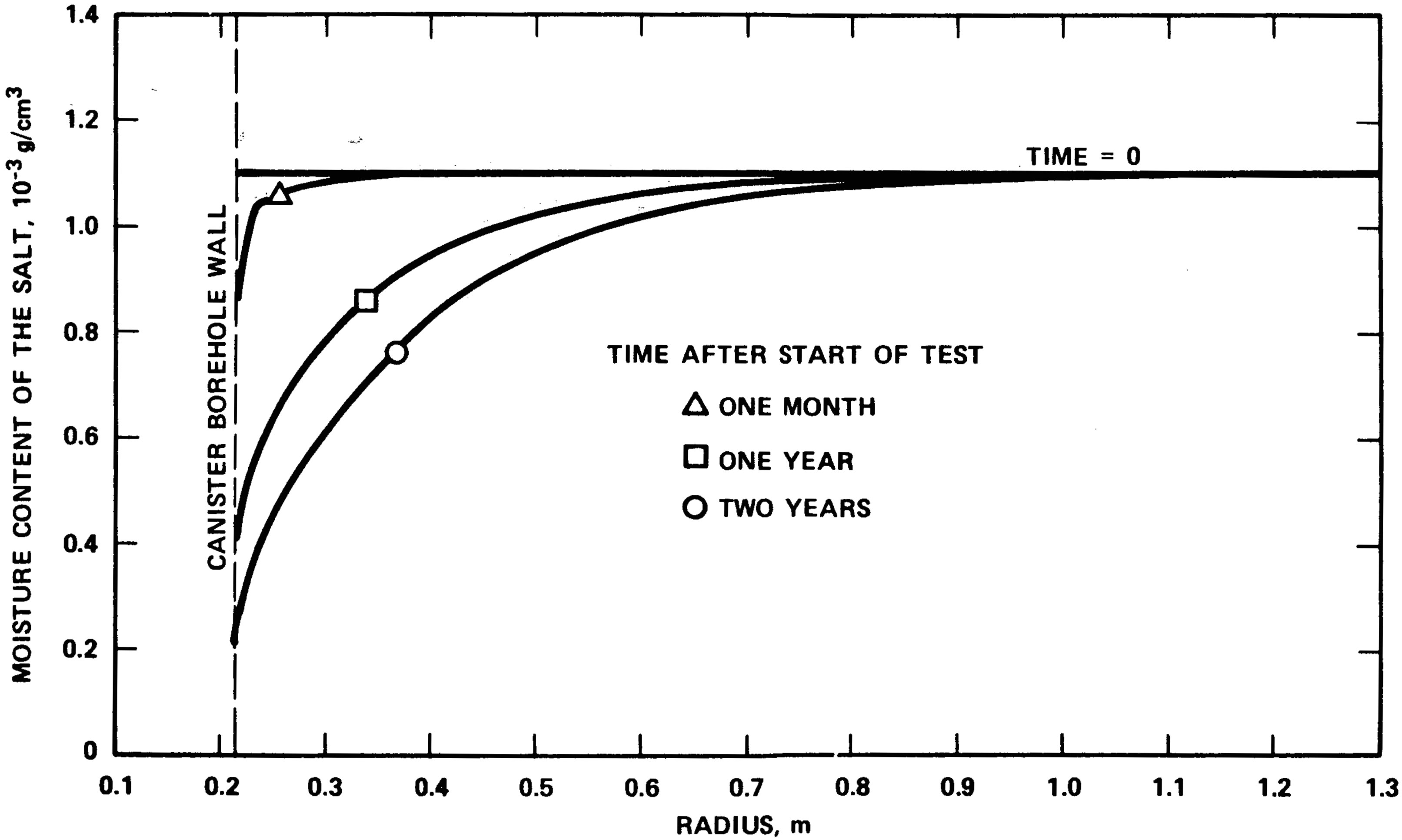

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Figure 6-15. Liquid Inclusion Migration, Water Content of the Salt at Various Times at the Heater Midline

The total water collected indicates that, on the average over the test section, water was collected from up to 7 cm (2.8 in.) into the borehole wall over the two-year test interval. At the highest temperature region, the water would arrive from 12 to 15 cm into the salt. This is more than the assumed 5 cm (2 in.) thick disturbed region around the borehole and should provide representative results. It is noted that this mechanism is not expected to produce significant amounts of water at Asse due to the extremely low content of liquid water which could participate in liquid inclusion migration, but is intended to describe the results for other potential test sites. The total amount of water expected would be proportional to the water content of the salt, but the collection radius would be unchanged. It should also be noted that these calculations are not representative of repository conditions because both the temperature distributions and the times are different from the conditions evaluated here, thus the test results must be used to qualify models which then could estimate repository performance.

6.5 VAPOR MIGRATION MODEL

A second model to describe motion of water in salt is the vapor migration model. This model assumes that motion of water in the salt takes place by motion of water vapor through pore spaces in the salt. The water vapor is formed by evaporation of water from brine or from hydrated minerals in the salt. Transport of water vapor is due to either pressure differences (Darcy or Knudsen flow) or by water vapor concentration differences at constant total pressure (diffusion flow).

This model is developed for cylindrical coordinates in which only Darcy flow is currently being modeled. In the future, other flow mechanisms will be studied.

The vapor source term can be rather complicated in salt. If the water in the salt exists as a concentrated brine solution, the vapor pressure of the water will be reduced compared to that of pure water due to the effects of the dissolved solids. Water present as hydrated minerals will also have a vapor pressure as a function of temperature.

For the purpose of this study, the water is assumed to be present as concentrated brine solutions and the effect of reduced vapor pressure is considered. When the water begins to evaporate from the brine, the salts will become more concentrated, further lowering the vapor pressure of the water. The dominant constituents of brine inclusions are likely to be sodium chloride, which is always at saturation due to being in contact with solid sodium chloride, and magnesium chloride. The magnesium chloride is likely present at levels well below saturation, but as the water evaporates, the magnesium chloride will become more saturated and, thus, further lower the vapor pressure. According to information from Jenks (1980), which is reproduced here as Figure 6-16 and 6-17, the vapor pressure of concentrated solutions of sodium and magnesium chloride can be below atmospheric pressure, even at temperatures of 200°C. Figure 6-18 is developed from these previous figures and presents the vapor pressure of brine which initially was saturated with sodium chloride and contained 2 molal magnesium chloride versus the fractional amount of water remaining in the brine after evaporation of some of the water. The data are presented for several different temperatures and demonstrate the severe vapor pressure depression of concentrated brines. These data also indicate that not all of the water would be evaporated if the pressure in the borehole is atmospheric pressure. The data also indicate that a discrete evaporation front will not occur in salt as would happen with drying of a material containing pure water.

Based upon the preceding discussion, it is clear that the remaining brine solution in the salt must be in local vapor pressure equilibrium with the water vapor flowing past the brine. At constant temperature, the vapor pressure can only be reduced locally if the brine at that location is further evaporated to reduce its vapor pressure. This is expressed as:

$$P_v = f\ (T,\ \rho_w) \qquad 6.5\text{-}1$$

where:

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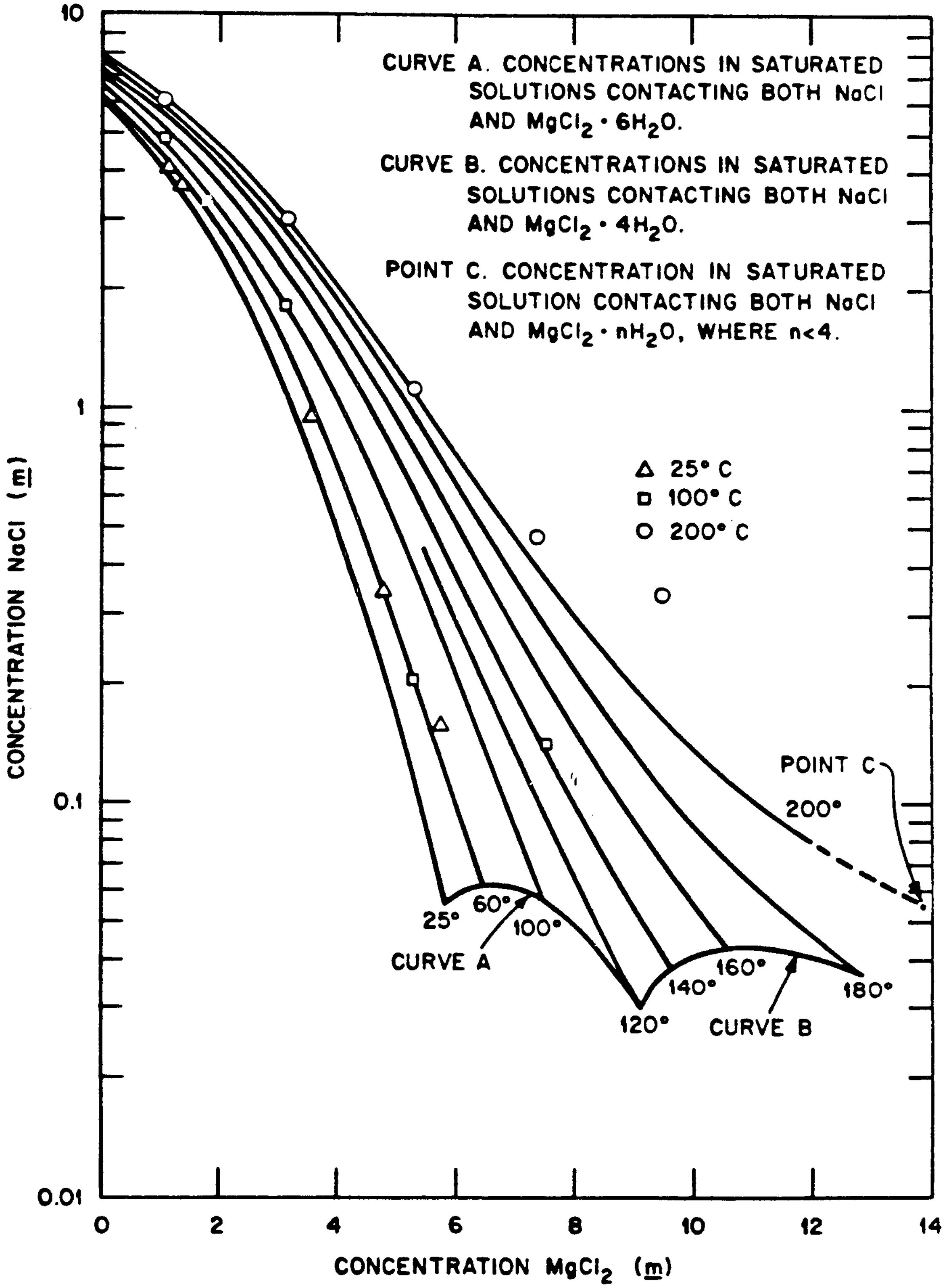

Figure 6-16. Calculated Concentration of $MgCl_2$ in Equilibrium With NaCl at Various Temperatures

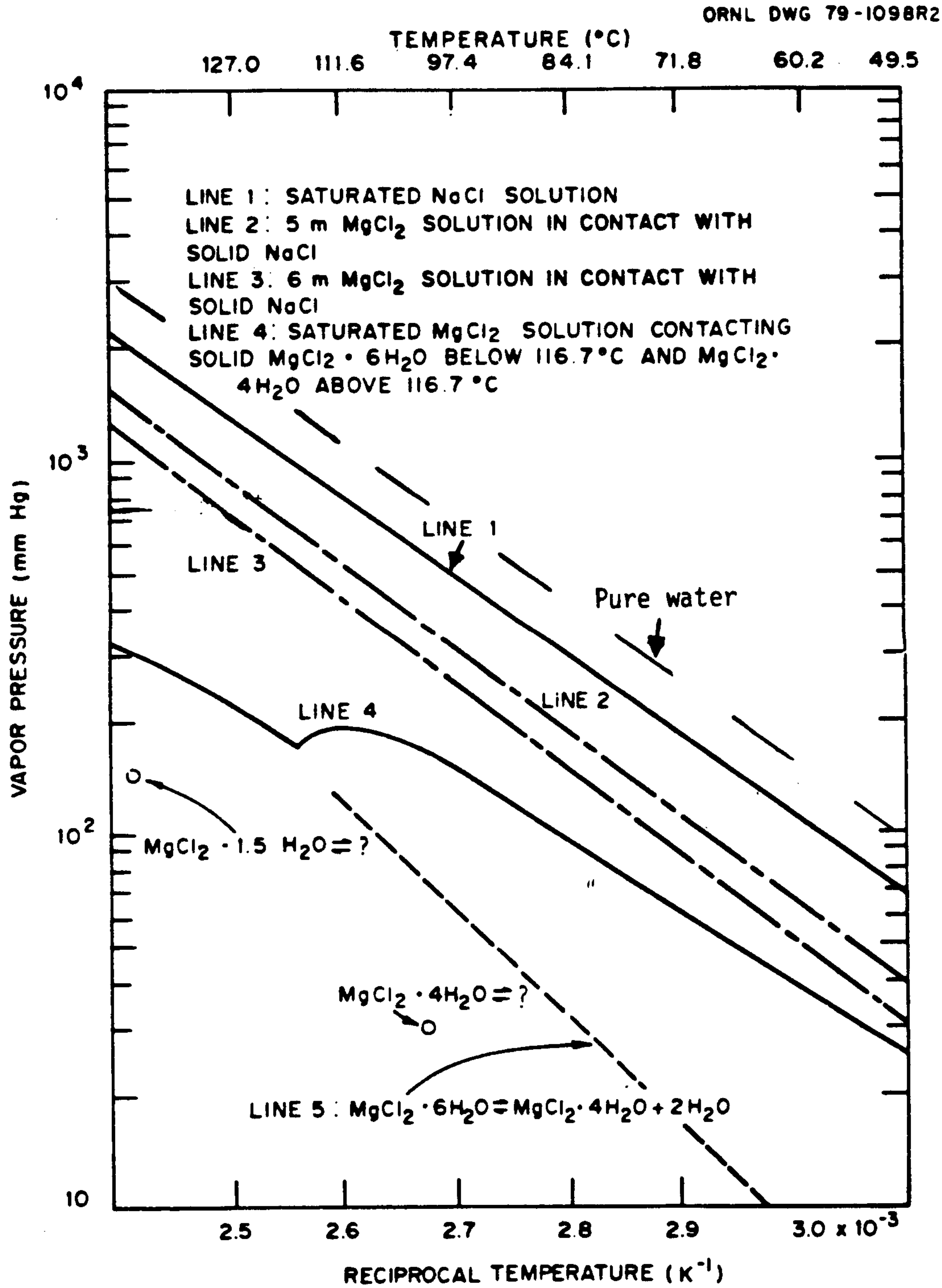

Figure 6-17. Vapor Pressure of NaCl and M_2Cl_2 Solutions at Various Temperatures

P_v = vapor pressure of water - atm

T = temperature - °C

ρ_w = local density of water in the salt - g/cm^3

f = a function relating water concentration in brine and temperature to the fluid vapor pressure

The motion of the water vapor is assumed for the present study to be driven only by variations in total gas pressure, and that the flow is proportional to the pressure gradient by Darcy's law (although other relationships may be considered in the future).

$$V = \frac{-k}{\mu} \nabla P_v \qquad 6.5\text{-}2$$

where

V = velocity of the water vapor - cm/sec

k = permeability of the salt - cm^2

μ = viscosity of the water - poise

P_v = water vapor pressure - $dynes/cm^2$

The equation for the conservation of mass states that a change in local water density in the salt is accompanied by spacial variations in the water vapor flow.

$$\frac{\partial \rho_w}{\partial t} = - \nabla \cdot \rho_v V_v \qquad 6.5\text{-}3$$

Finally, the perfect gas law is used to relate water vapor pressure, temperature, and density:

$$\rho_v = \frac{P_v}{RT} \qquad 6.5\text{-}4$$

where

R = the gas constant

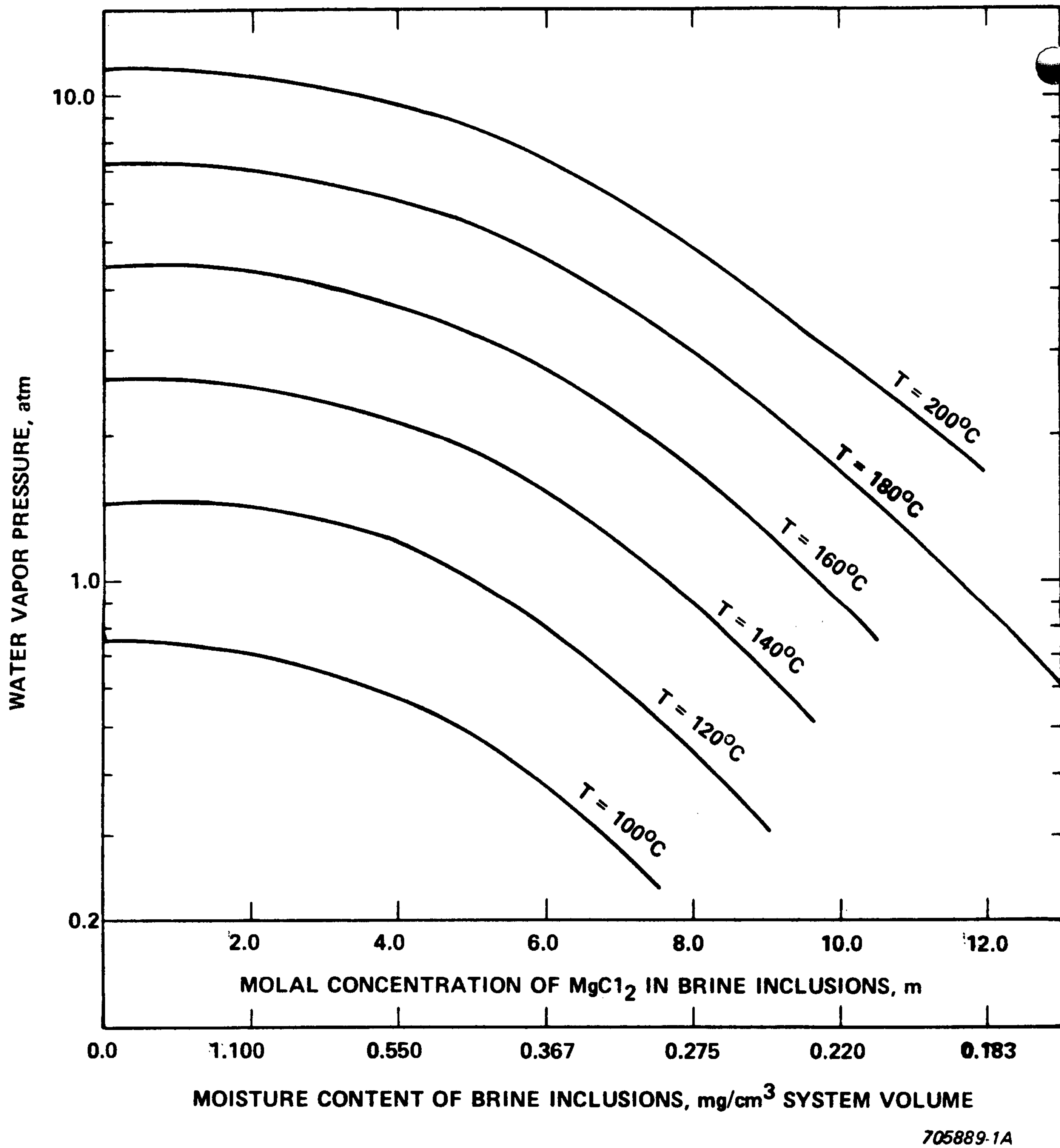

Figure 6-18. Vapor Pressure as a Function of Water Evaporated from Brine in Salt Initially Containing Two Molal $MgCl_2$

6.6 VAPOR MIGRATION RESULTS

These equations have been solved numerically using discrete space and discrete time for a axisymmetric cylindrical coordinates. In this solution, the borehole pressure is maintained at one atmosphere pressure. (Future analyses will consider the self-pressurizing borehole concept.) At the start of the solution, an initial water concentration of 0.05% wt (or 0.0011 g/cm^3) was imposed. The temperature distribution used in these calculations is as described in Section 6.2. Initially, there is no water vapor flow because the salt temperature is below 110° C. (At this temperature, the 2 molal brine solution will generate water vapor pressure of 1 atm.) Soon, water vapor started to flow into the canister. No outward water vapor flow was allowed because the salt pore spaces were assumed to be filled with fluid. At the first calculational node into the salt from the borehole, the high pressure gradient toward the borehole causes a vapor flow which reduces the water concentration and, therefore, the water vapor pressure in that node.

When the vapor pressure in the first node is reduced below that in the second node, vapor begins to flow from the second to the first then to the borehole. This process continues until, eventually, flow is produced from nodes distant from the borehole, as long as the local saturation pressure is above the borehole pressure.

The solution was developed for two salt permeability levels believed on the basis of available data (Sutherland and Cave, 1979) to be representative of the permeability in salt in the field, 1.0 and 0.1 μ Darcy. These results are shown in Figure 6-19 as total water arriving at the borehole over two years of testing. Figures 6-20 to 6-21 show the changes in local vapor pressure and water concentration in the salt over this transient time and Figures 6-22 and 6-23 show the water concentration remaining in the salt at various times.

Two conclusions are evident. The first is that a considerable amount of water is produced (4.7 and 1.9 liters for 1.0 and 0.1 μ Darcy permeability, respectively), even from this quite dry salt. The second is that water is collected

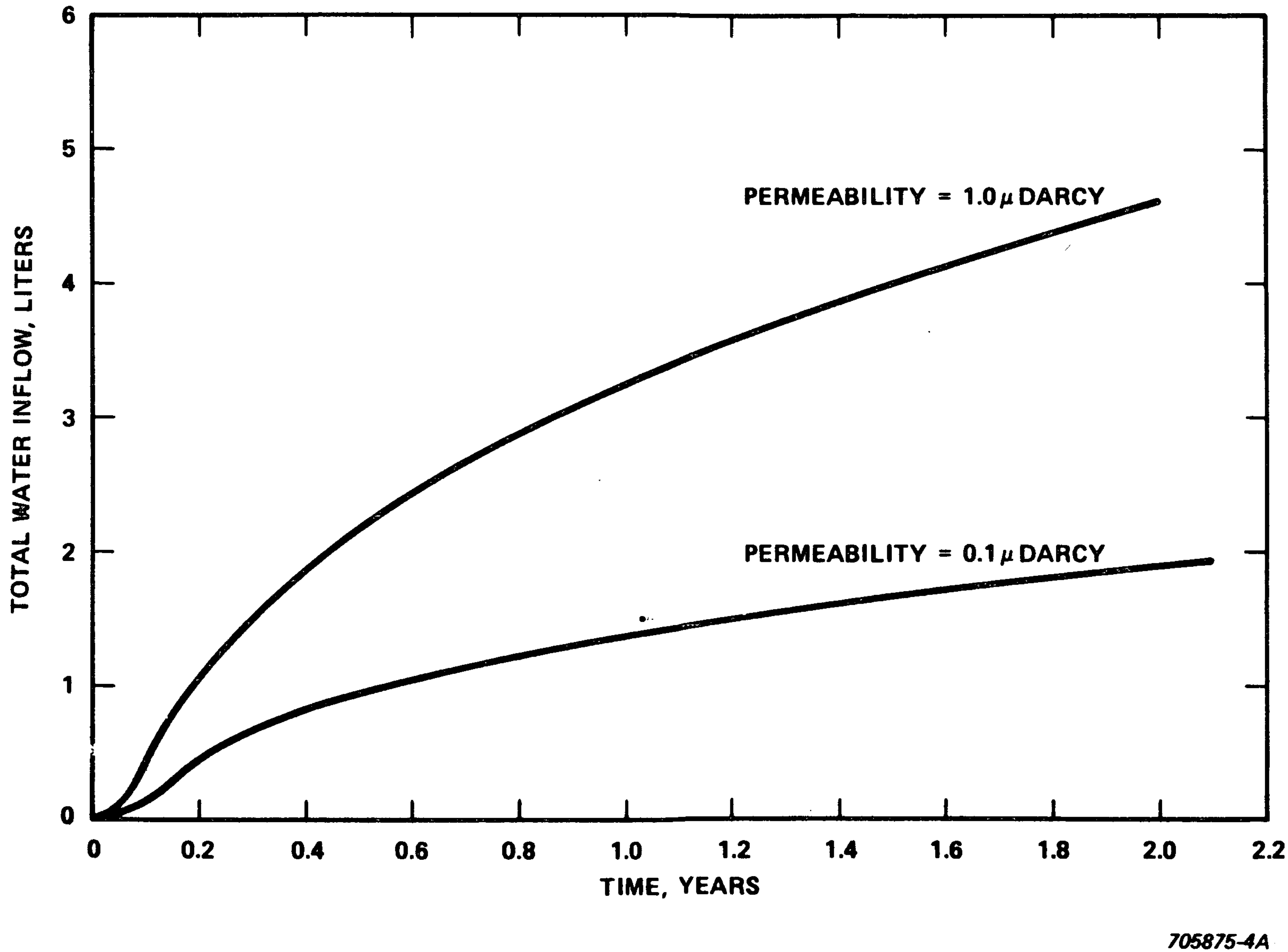

Figure 6-19. Vapor Migration, Calculated Water Production Assuming 0.05 Wt% Water Content of the Salt

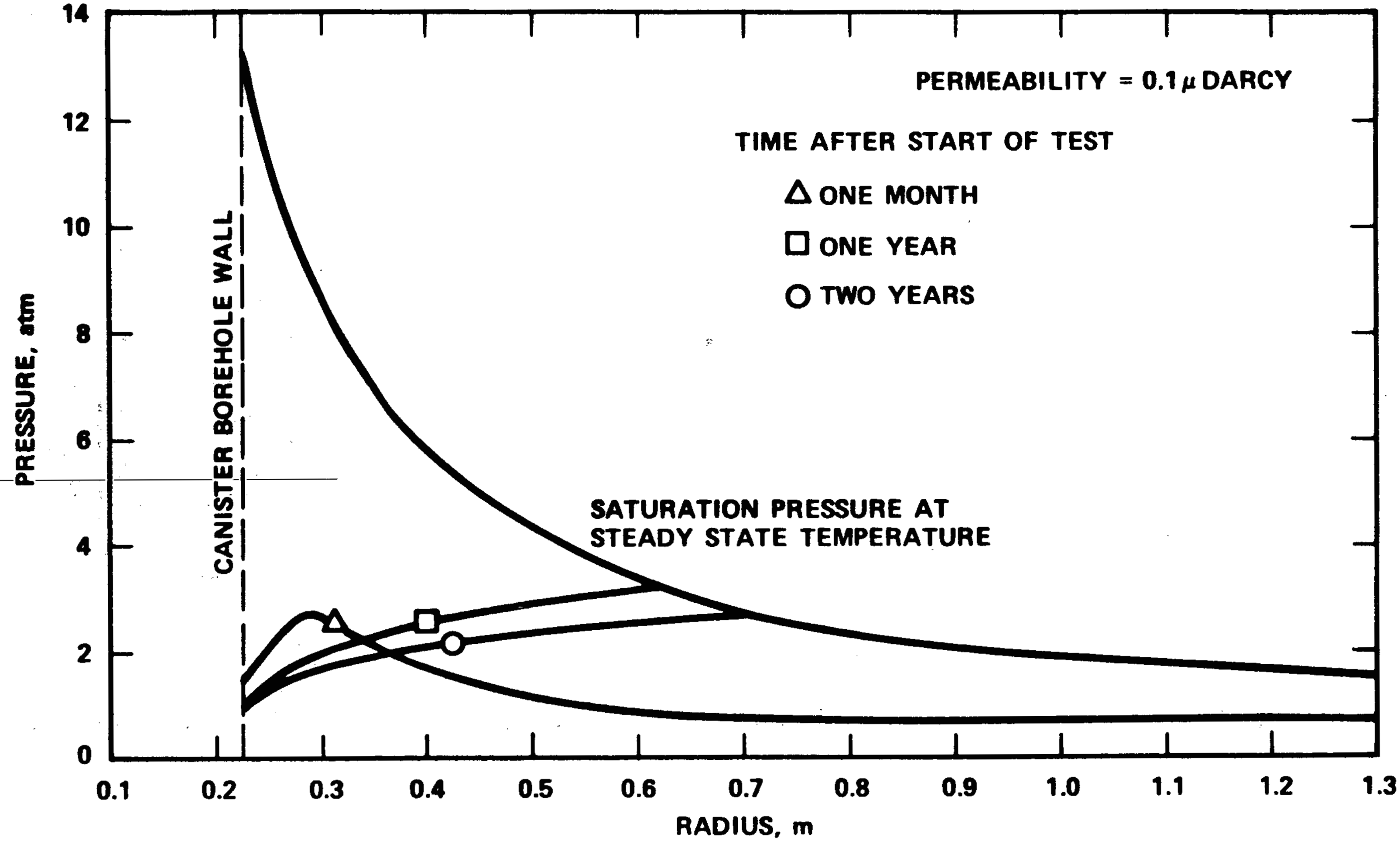

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Figure 6-20. Vapor Migration, Calculated Brine Vapor Pressures in the Salt at Various Times at the Heater Midline With 0.1 μ Darcy Permeability

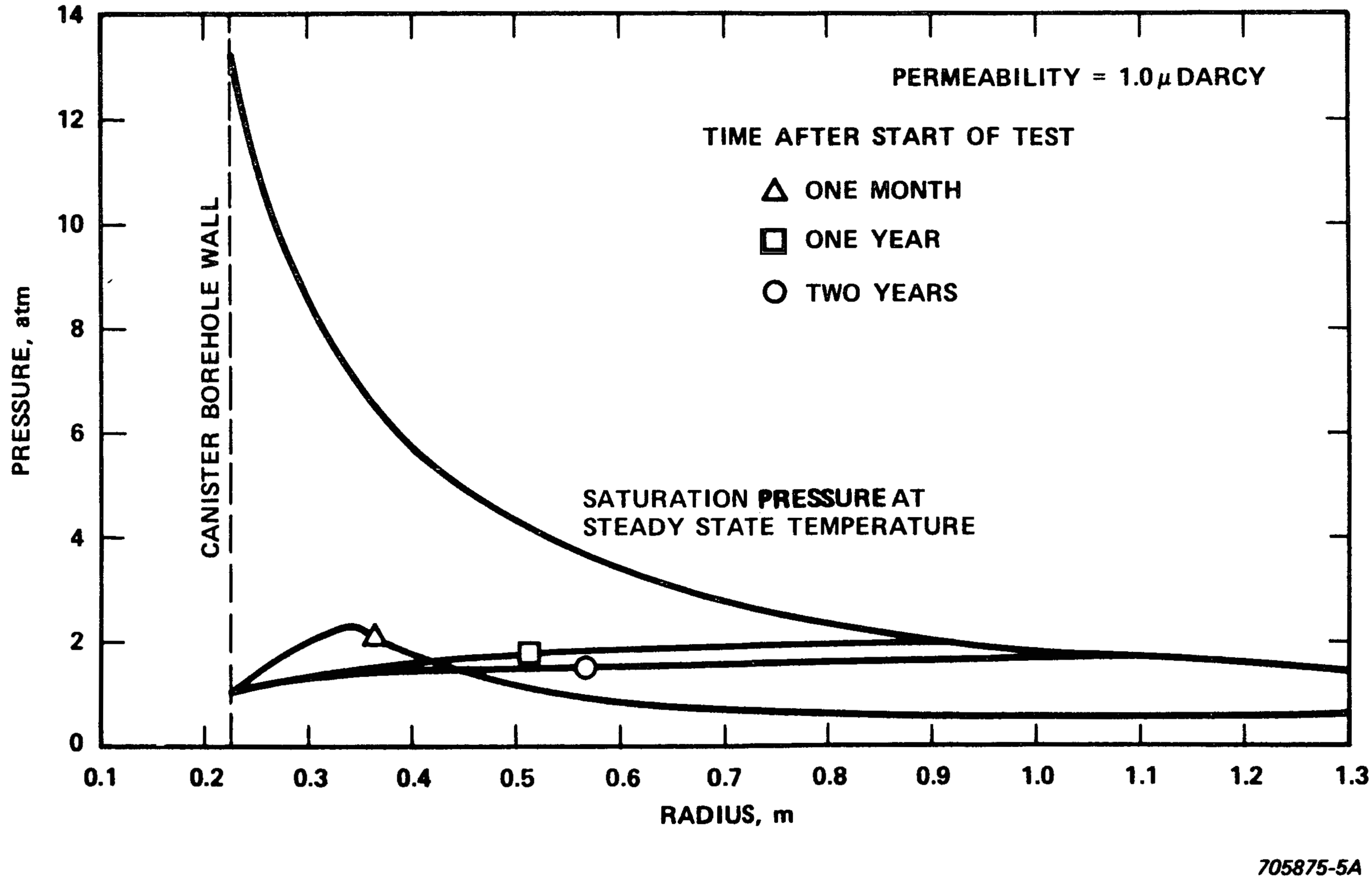

Figure 6-21. Vapor Migration, Calculated Brine Vapor Pressures in the Salt at Various Times at the Heater Midline With 1.0 μ Darcy Permeability

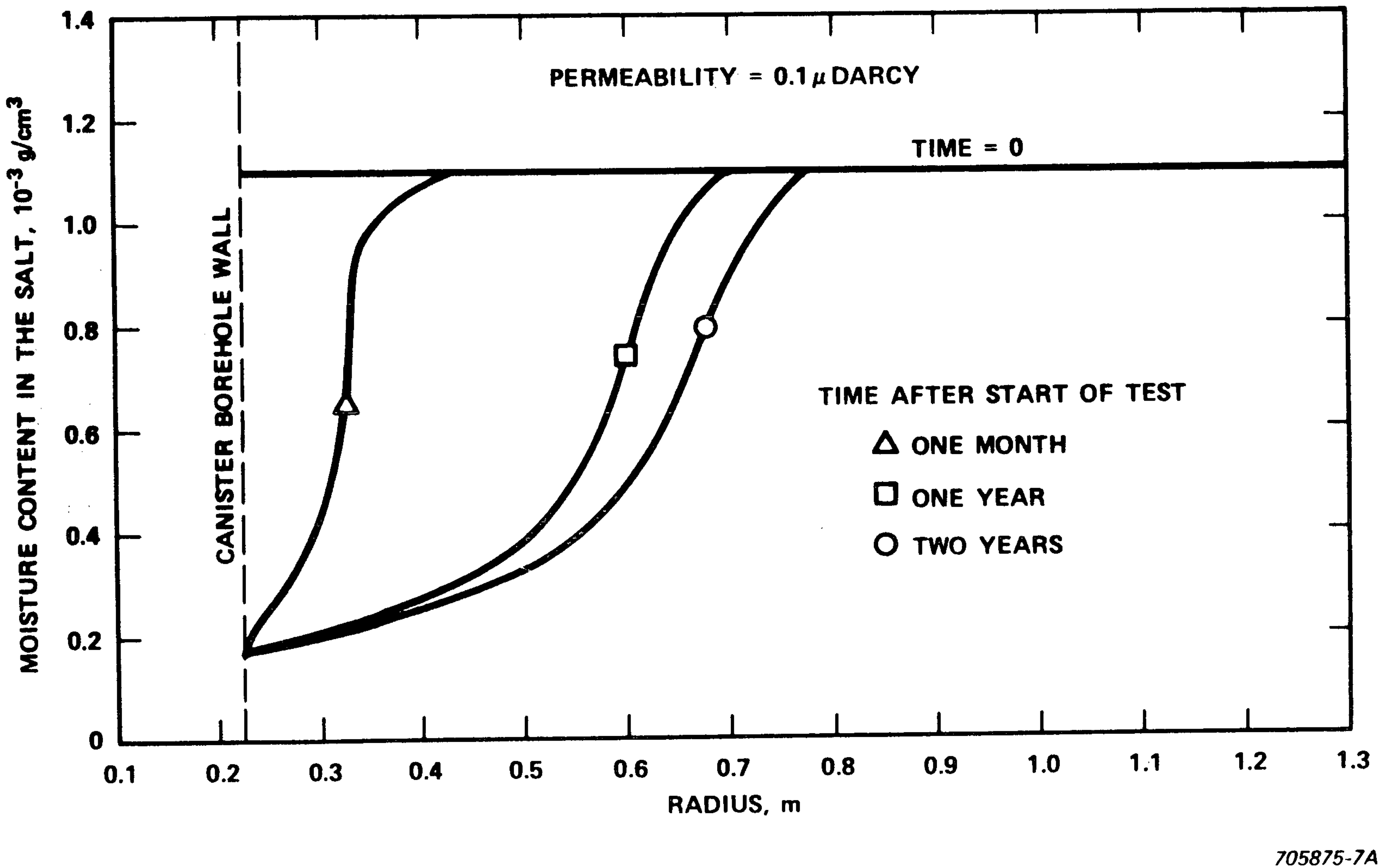

Figure 6-22. Vapor Migration, Calculated Water Content in the Salt at Various Times at the Heater Midline With 0.1μ Darcy Permeability

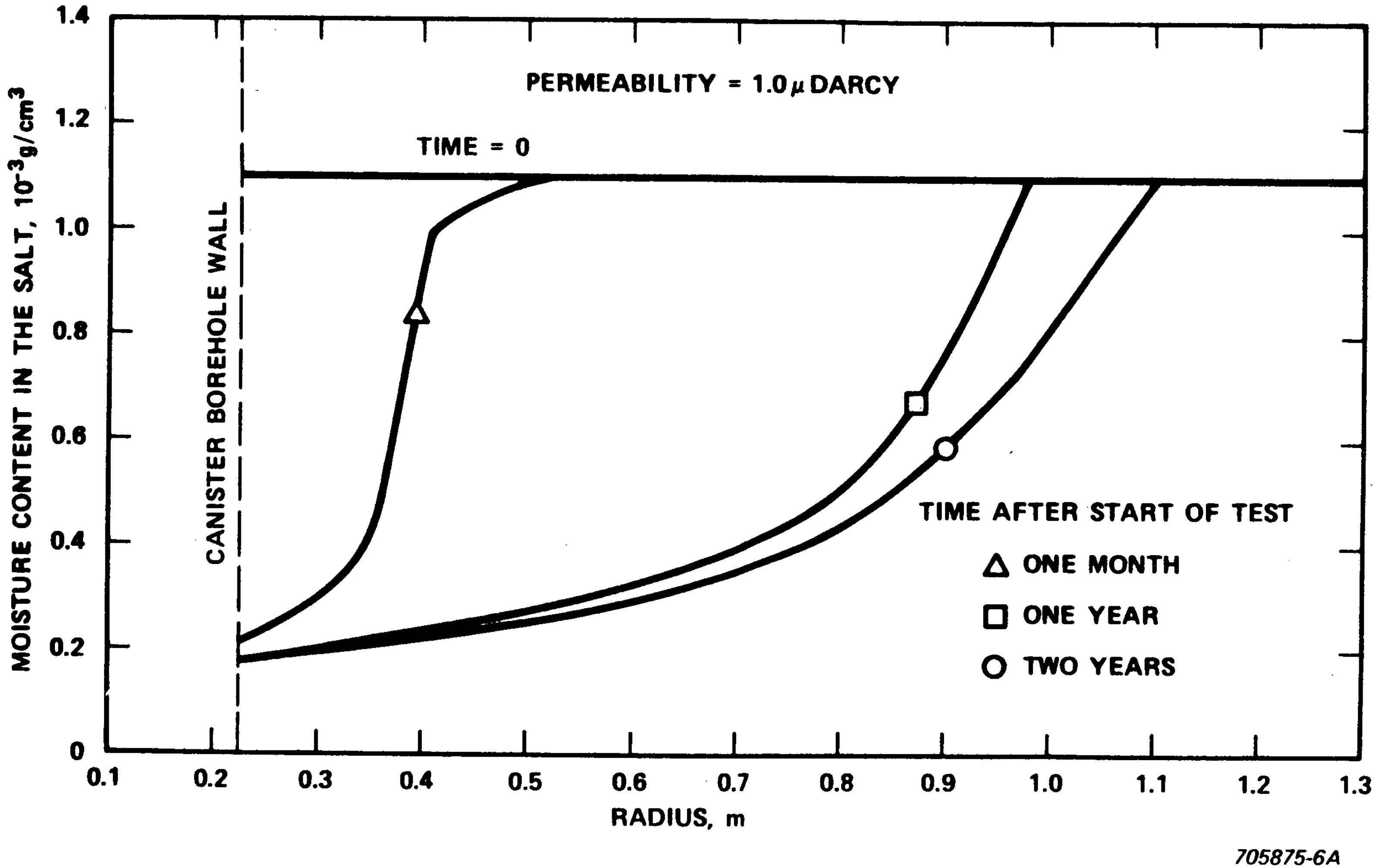

Figure 6-23. Vapor Migration, Calculated Water Content in the Salt at Various Times at the Heater Midline With 1.0μ Darcy Permeability

from a large distance (80 to 110 cm from test centerline) into the salt. The limit on total water production for this test for the higher salt permeability, is determined largely by the total amount of water in the salt heated to above a saturation pressure of 1 atmosphere. The guard heaters are at a radius of 1.5 meters and should be sufficiently beyond the zone of water collection so as not to influence the test results.

6.7 RADIATION ANALYSIS: ASSUMPTIONS AND METHODS

Radiation analyses were done to predict doses or dose rates in three areas of interest: the walls of the borehole, the seal region, and the top surface of the installation. This section describes the assumptions and methods used in the analyses.

6.7.1 Assumptions

The assumptions given below were used in the analyses:

- The irradiation period is two years.
- The dose delivered in two years to the salt at the wall of the borehole should be 6×10^8 rads.
- The two colinear Co^{60} sources have the following characteristics:
  - activity of the Co^{60} is uniform along the active regions of the sources,
  - length of radioactive region is 818 mm (32.2 in),
  - diameter of cobalt is 9.5 mm (0.37 in),
  - combined wall thickness of steel jackets is 1.6 mm (0.063 in),
- The distance between adjacent ends of the active regions of the two sources is 178 mm (7.00 in).
- The porous medium in the annulus between the sleeve and the wall of the borehole is Al_2O_3, whose density is 3.97×10^3 kg m^{-3} (248 lbs-ft^{-3}). Al_2O_3 fills 65% of the volume of the annulus.

- The thicknesses of the attenuating materials between the source rods and the wall of the borehole are:
  - steel wall of source support tube, 4.0 m (0.156 in);
  - steel wall of canister, 3.2 mm (0.125 in);
  - steel wall of heater support tube, 2.8 mm (0.109 in);
  - steel wall of sleeve, 19.1 mm (0.75 in);
  - Al_2O_3 filled annulus, 50.8 mm (2.00 in).
- The thickness of each end cap on the steel is 25.4 mm (1.00 in).
- The radius of the borehole in the salt is 217 mm (8.56 in).
- The density of the salt is 2.2×10^3 kg m^{-3} (137 lbs-ft^{-3}).
- The density of the steel is 7.86×10^3 kg m^{-3} (491 lbs-ft^{-3}).

6.7.2 Methods

Radiation Dose to Salt

The dose rate at the wall of the borehole was calculated by representing each of the two Co^{60} source rods as a string of ten, equally-spaced, point sources. The incremental dose rates from each of the point sources was calculated at a field point along the wall. The calculation allowed for attenuation of the radiation by intervening layers of materials; the attenuation calculations included the conventional buildup factor caused by photon scattering. The end caps on the canisters were ignored. The incremental dose rates from the point sources were then summed to obtain the dose rate at the field point.

The integrated dose delivered over the two year radiation period was then calculated for a field point opposite the center of the upper Co^{60} rod. This calculation allowed for the 5.27 year half-life of the Co^{60}. The resulting dose was used to adjust the strength of the Co^{60} sources so that the integrated dose would be 6×10^8 rads. Using the adjusted source strength, the dose distribution at the wall was calculated as a function of the vertical distance from the midpoint between the sources.

Radiation Dose to Seal Regions

The direct dose to the seal regions was calculated using the string of point sources as described above.

The indirect dose was calculated using the dose rate distribution in the salt at the level of the top of the upper source as the indirect radiation source. Allowance was made for attenuation by the materials between this source and the seal regions.

Radiation Dose Rate at the Surface of the Installation

The direct dose rate at the level of the top of the shield plug was calculated using the string of point sources as described previously. Allowances were made for attenuation of the dose rate by the steel end caps on the canisters, by the minimum thickness of steel in the internal shield (184 mm (7.25 in)), and by the thickness of steel in the shield plug (254 mm (10 in)). No allowance was made for attenuation by the insulating material in the internal shield.

The indirect dose rate was calculated using the same method as the one used for the seal regions.

Dose rates caused by radiation streaming through penetrations in the top plug were also calculated. The source for the streaming radiation was assumed to be radiation emerging from the material that can be viewed through the penetration.

6.8 RADIATION ANALYSIS: RESULTS

The following results were obtained from the analyses described in the preceding section.

Radiation Dose to Salt

The activity required in each of the two Co^{60} sources at the time of insertion into the borehole was estimated to be 9040 curies. This activity will deliver a maximum dose of 6×10^8 rads in two years to the salt at the wall of the borehole. The source activity is less than the 9430 curies given in Section

5.4.1. The latter activity allows for decay of the source for four months prior to insertion into the borehole and approximately represents the activity that would be ordered.

Using 9040 curies as the strength of each of the Co^{60} sources, calculations showed the distribution of the radiation dose to the salt at the wall of the borehole to be as shown in Figure 6-24. The solid portion of the dose distribution curve is believed to be reliable (± 20%). The broken line portions of the curve are not reliable because the dose in these regions will be reduced below the values shown by attenuation caused by the end caps on the canister. No allowance was made for the end caps in the derivation of Figure 6-24.

Small changes in the dimensions and spacing of the sources will not cause large changes in the dose distribution from the distribution shown in Figure 6-24.

<u>Radiation Dose to the Seal Regions</u>

The maximum two-year doses to the O-ring seal region from direct and indirect radiation were estimated to be:

direct dose	3.4×10^5 rads
indirect dose	4.5×10^4 rads
total dose	3.9×10^5 rads

The direct dose is an overestimate of what will be encountered because no allowances were made for attenuation by the end caps on the canisters or by the internal shield. Such allowances would reduce the direct dose substantially, but would not affect the indirect dose.

The maximum two-year doses to the castable seal region were estimated to be:

direct dose	2.7×10^4 rads
indirect dose	3.9×10^4 rads
total dose	6.6×10^4 rads

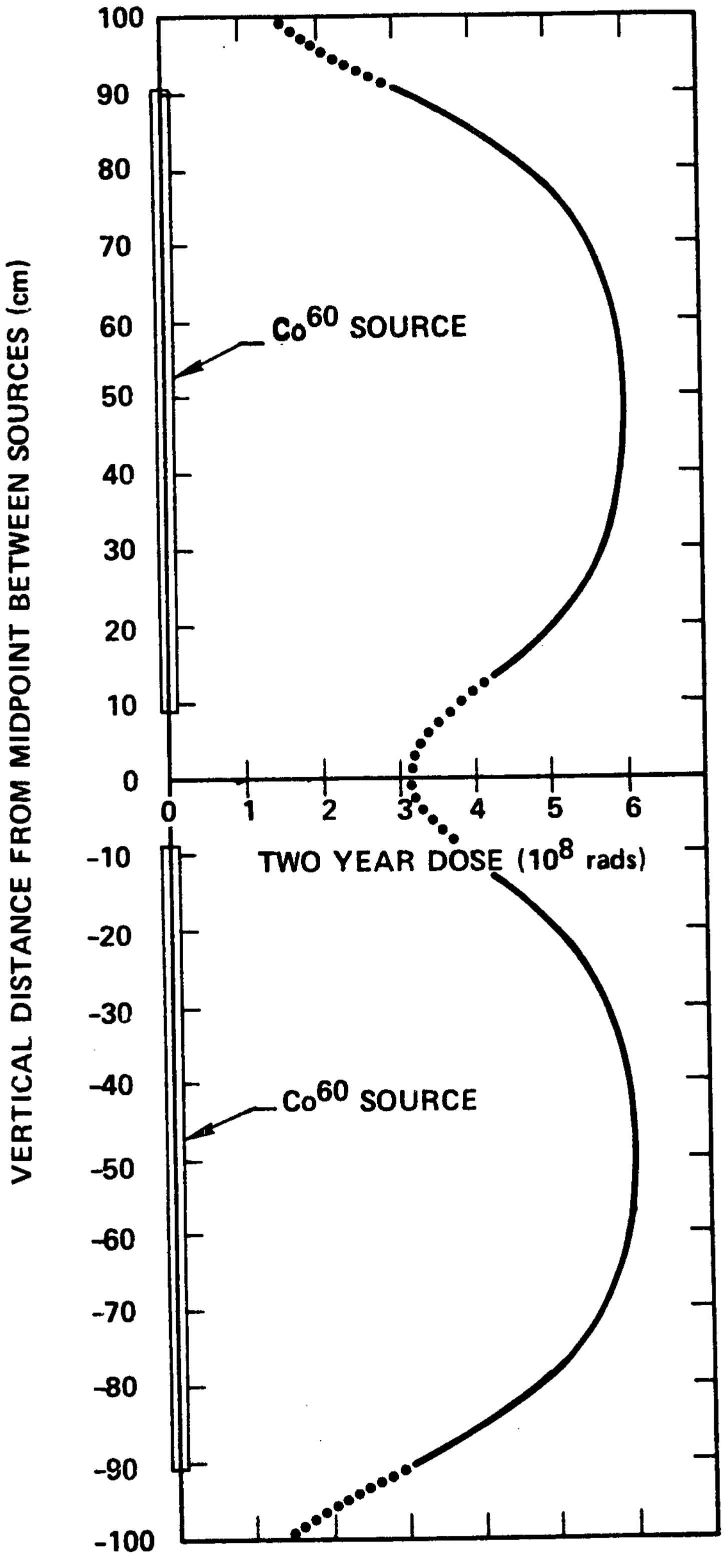

Figure 6-24. Two Year Radiation Dose at Wall of Borehole in Salt. Initial Activity of Each Cobalt 60 Source, 9040 Curies

The direct dose is again an overestimate for the same reasons as were given for the O-ring region.

Dose Rates at the Surface of the Installation

Dose rates were calculated at the level of the top of the shield plug. The maximum dose rates were estimated for three configurations related to the placement of the internal shield and the shield plug.

Configuration	Dose Rate (mrem hr^{-1})
1. Both internal shield and shield plug in place	1
2. Internal shield in place, shield plug absent	3×10^3
3. Both Internal shield and shield plug absent	1×10^6

The dose rate shown for Configuration #1 includes the maximum dose rate caused by radiation streaming through a penetration. This dose rate is 0.8 mrem hr^{-1} and occurred above an open penetration for a heater conductor.

The dose rates shown for the three configurations are attributable to direct radiation from the Co^{60}. Indirect radiation does not contribute significantly to the dose rate.

6.9 SALT THERMAL MECHANICAL ANALYSIS

6.9.1 Introduction

An integral part of the test design development is the thermal mechanical interaction analysis of the salt and test assembly to provide design inputs and design philosophy and to verify the design assumptions. The main objectives of the analysis are to provide information pertaining to:

- Hardware performance requirements - Such as the pressure conditions on the test equipment.

- Understanding of impact of heatup and cooldown, particularly with regard to potential for fracture or discontinuity development in the salt since fracturing may have direct impact on brine migration and may make it impossible to seal the test zone.

- Placement configuration - Specifically with regard to the depth of the test zone below the floor of the test room and the minimum distance between test sites.

- Stresses and deformations in the sealing zone to establish heater hole casing and sealing requirements.

- The possibility of gas pressure in the test zone causing fracturing of the host salt.

This section provides a summary of the above analysis. Further details will be included in an upcoming technical report.

6.9.2 Input and Assumptions

6.9.2.1 Test Setup and Environment

The basic test setup described in Section 5 has been analyzed. The test room is 10 meters wide and 6 meters high. The heater depth is from 3.8 to 5.7 meters below the room floor. Between the heater and the mine room floor is a carbon steel sleeve and seal. Guard heaters are located at a radius of 1.5 meters and extend from a depth of 3.0 to 6.5 meters below the mine floor. The radius of the central heater hole is 0.217 meter.

To model the test setup for the thermomechanical analysis, it was necessary to consider the following two aspects of the location and configuration of the test area:

- Potential effects of previously mined rooms at higher levels, which are either backfilled, partially backfilled, or open, on the initial state of in situ stress prior to starting the experiments, and

- The degree of coupling which may exist between tests because of the spacing of the heater holes and layout of the test rooms.

The test room is at 800-meter level. It is known that at the 775-meter level in the vicinity of the test area, old rooms have been excavated and backfilled more than 50 years ago. Analysis and experience with similar salt mines indicate that 50 years is a sufficient time for these rooms (at 775-meter level) to close due to creep so that they will not impact the behavior of test rooms at 800-meter level. Also, the impact of the open or partially backfilled rooms at higher levels (750-meter level, in particular) is insignificant. Consequently, existing rooms will not significantly affect the existing state of stress at the start of the experiment. It is anticipated that a hydrostatic state of stress will exist at sufficient distance (15 meters) from the test room.

Boundary conditions at the outer boundaries of the model were thus assumed to correspond to a hydrostatic stress corresponding to a depth of 800 meters.

In general, spacing of the test rooms as well as heater holes within a single room can lead to coupling effects which may affect the state of stress around the experiments. To investigate the effects of room spacing, an analysis was performed as described in Section 6.9.3. This analysis indicated that the minimum spacing between experiments in parallel galleries to preclude coupling effects is 30 meters with 20 meter pillars. Also, the current spacing of 15 meters between test holes in a single gallery is sufficient to preclude significant interaction. The model used for the thermomechanical analysis of stresses induced by the experiment was based on the assumption of no interaction between rooms or other experimental setups.

6.9.2.2 Time Sequence for Various Stages in the Test

Based on the currently anticipated approximate schedules of the test procedure, the following time sequence has been assumed for the various test stages:

Day 0^-	- Existing in situ hydrostatic state of stress
Day 0^+	- Test room is created
Day 365	- Heater hole is drilled
Day 421	- Heater assembly is placed into the heater hole without having either any gaps or significant stresses against the wall
Day 421	- The main and guard heaters are turned on to full power
Day 1151 to 1179	- The power of the main and guard heaters is reduced to zero in eight equal steps
Day 1179 to 1186	- The power remains off

The impact of drilling of the guard heater holes is anticipated to be minimal and was not analyzed in detail.

6.9.2.3 Thermal Properties and the Behavior

The heat transfer analysis, the associated assumptions, thermal properties, etc., have been discussed in Sections 6.1 and 6.2 and the results are shown in those sections. To include a cooldown phase, the original heat transfer analyses were repeated using the mesh for the stress analysis, Figure 6-28.

The temperature dependent thermal conductivity and specific heat of salt as described in Section 6.1 were used. The equivalent thermal conductivity used for the heater and the sleeve is 1.58 W/m-°C, and the corresponding specific heat capacity is 8.0×10^5 $J/m^3 °C$. The equivalent thermal properties account for the properties of various materials (Inconel, steel, alumina beads) and the presence of voids. The thermal coefficient of expansion for the salt, heater segment including alumina beads, and the sleeve are respectively 4.0 x 10^{-5}, 1.35 x 10^{-5}, and 1.35 x 10^{-5}/°C and are not considered temperature dependent.

6.9.2.4 MECHANICAL PROPERTIES

The equivalent Young's modulus for the heater segment and the sleeve is 7,758 MPa (1.1 x 10^6 psi) with a Poisson's ratio of 0.30 based on the cross section of the heater assembly.

The Young's modulus used for the salt is 6,896 MPa (1 x 10^6 psi). This value is difficult to define since it varies with stress condition and rate of loading. Values in the literature range from 1,379 MPa (2 x 10^5 psi) to 34,480 MPa (5 x 10^6 psi). The higher values generally correspond to seismic (rapid) loading conditions with small strains. Wallner (1979) reports a reduction in modulus from 13,920 to 6,600 MPa for German salt as the temperature increases from 27 to 210 degrees Centigrade. Because the temperature near the heater will be near 200 degrees Centigrade, a modulus near 7,000 MPa is more appropriate. Considering all of the above, a constant modulus of 6,896 MPa has been selected for salt with a Poisson's ratio of 0.4. However, the sensitivity of maximum radial stress on the heater assembly to modulus value was evaluated for a modulus of 13,792 MPa (2 x 10^6 psi).

Based on laboratory tests, the creep behavior of salt is described in two distinct parts:

- Primary creep which is transient in nature and governs for a short time following application of load, and
- Secondary creep which is steady state in nature following the decay of the transient primary creep.

Laboratory experiments for the determination of creep behavior are often constant stress tests in which a constant load is applied and creep allowed to occur as a function of time. This constant stress state is not applicable to the in situ behavior of salt subjected to temperature gradients. Thermally induced stresses are a result of compatability requirements which change as temperatures change and are not the same as constant mechanical stresses imposed in the laboratory. In view of these conditions, the effects of primary creep were neglected as leading to negligible errors.

The steady state (secondary) creep behavior of salt was modeled using the following relationship:

$$E_s = A \exp(-Q/RT)\, s^n$$

where:

E_s = secondary creep rate (day^{-1}),
A = material parameter ($MPa^{-n} \cdot day^{-1}$),
Q = activation energy ($KJ \cdot mol^{-1}$),
R = universal gas constant (8.314×10^{-3} $KJ \cdot mol^{-1} \cdot K^{-1}$),
T = absolute temperature (K),
s = deviator stress (MPa), and
n = material parameter.

For halite from the Asse salt mine, the following parameters were used:

Q = 54.21 ($KJ \cdot mol^{-1}$),
A = 0.18 ($MPa^{-5} \cdot day^{-1}$), and
n = 5.0.

The above relationship was developed for Asse salt based on the laboratory experiments (Hunsche, 1979). A preliminary effort to verify the above relationship by comparing predictions from the above creep law against some actual observations is currently underway.

6.9.3 Model and Analysis Results

Two models were used for the analyses. First, a large-scale vertical plane strain model was developed to evaluate the impact of the surrounding rooms and the boundary stresses for the smaller scale model near the heater. Secondly, a small-scale axisymmetric model (Figures 6-27 and 6-28) around the test heater was used to evaluate the detailed behavior around the test heater. In addition, several one-layer axisymmetric models were analyzed to check the impact of the boundary condition assumptions and finite-element grid refinement and to provide an overall check of the results.

The plane strain model indicated that the stress at the boundary of the smaller axisymmetric model is not affected significantly by either the creation of the test room or by creep around the test room. Based on this analysis and considering normal lithostatic stress, a constant normal boundary stress near 17.9 MPa (2,600 psi) has been used for both the vertical and horizontal boundaries of the axisymmetric model (Figure 6-28).

The heat transfer analysis for the axisymmetric model was performed using the parameters discussed previously and using the finite element computer code GEOFLOW. The results are shown in Figures 6-25 and 6-26 and are essentially the same as those reported in Section 6.2 from independent analyses.

The axisymmetric model was then used to perform the thermomechanical analysis based on the temperatures determined from the heat transfer analysis and the initial stress conditions described above. D'Appolonia's finite-element, rock mechanics computer code, DAPROK, was used to perform the calculations. The model starts with an axisymmetric block of salt preloaded with the boundary stresses. Creation of the test room opening is then simulated by the removal of those elements corresponding to the room. Creep is then allowed to occur over a 365-day period prior to drilling the heater hole. Drilling of main heater borehole is then simulated by removal of the corresponding elements from the model. The placement of the test assembly is simulated by adding equivalent elastic elements on Day 421 (following creep around the open borehole for a period of 56 days). A no-slip condition was assumed to exist between the test assembly and the salt borehole wall.

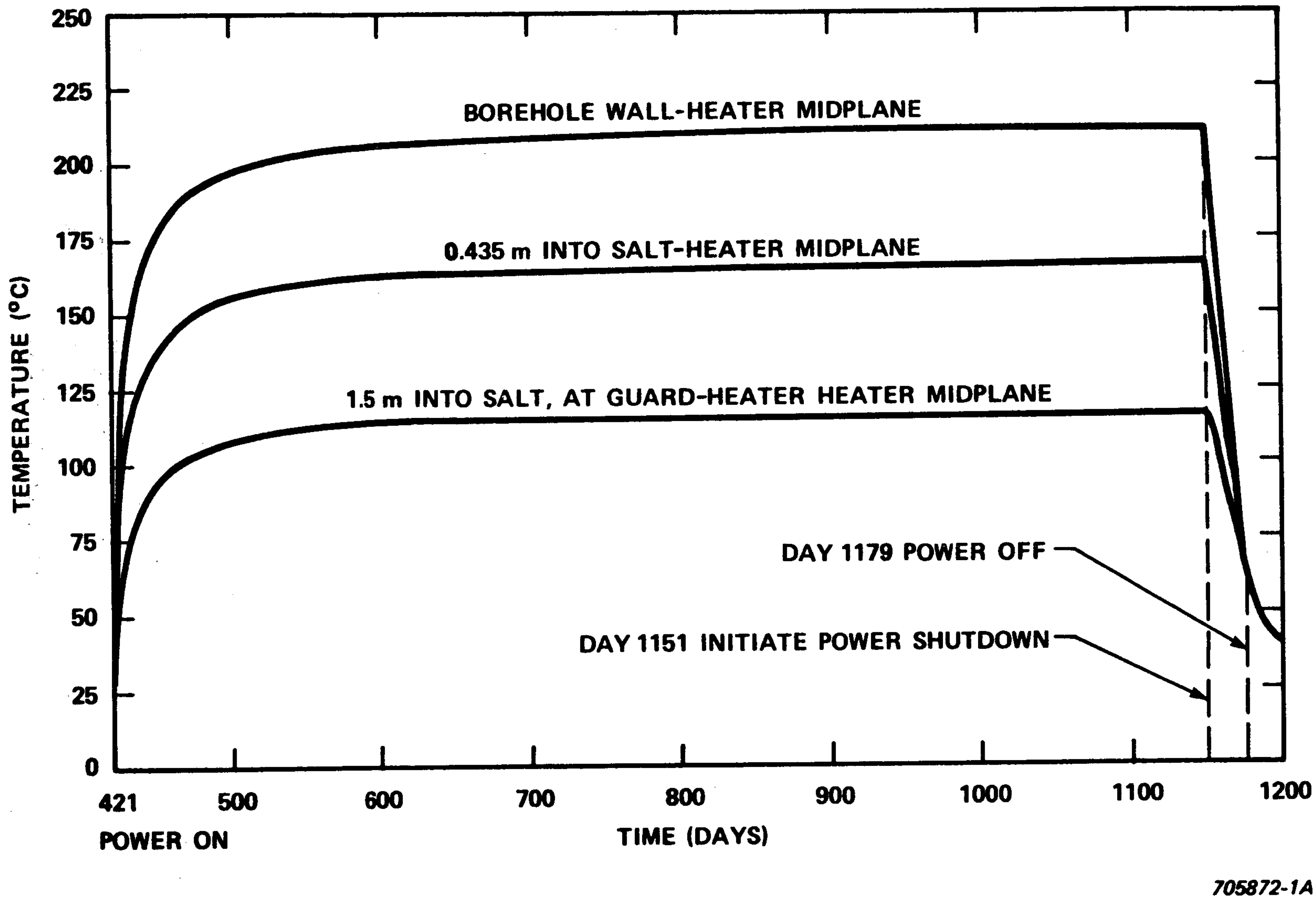

Figure 6-25. Heatup and Cooldown Temperature Transient Calculated for Salt Stress Analysis

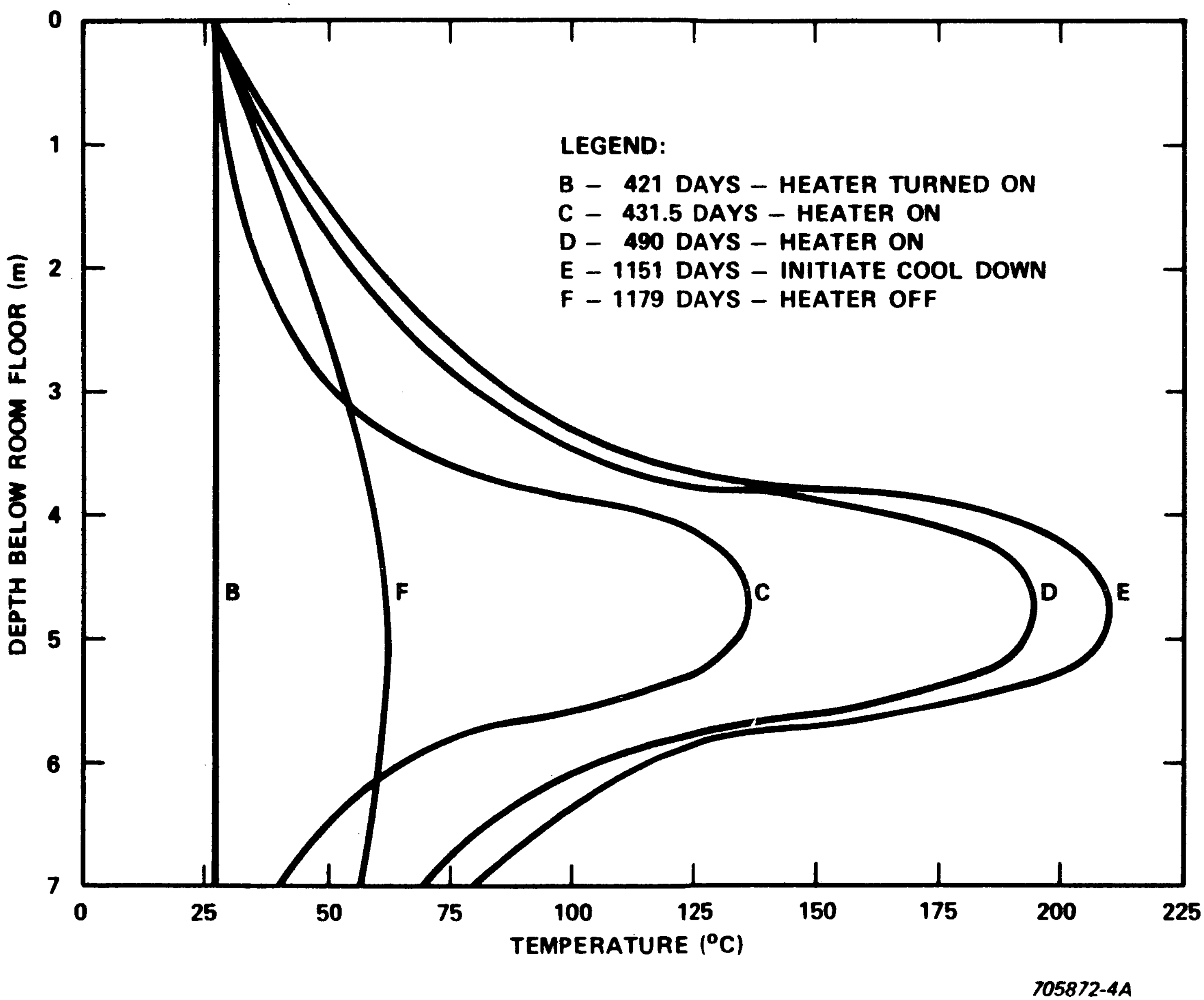

Figure 6-26. Temperature Along Salt Borehole Wall at Various Times for Salt Stress Calculations

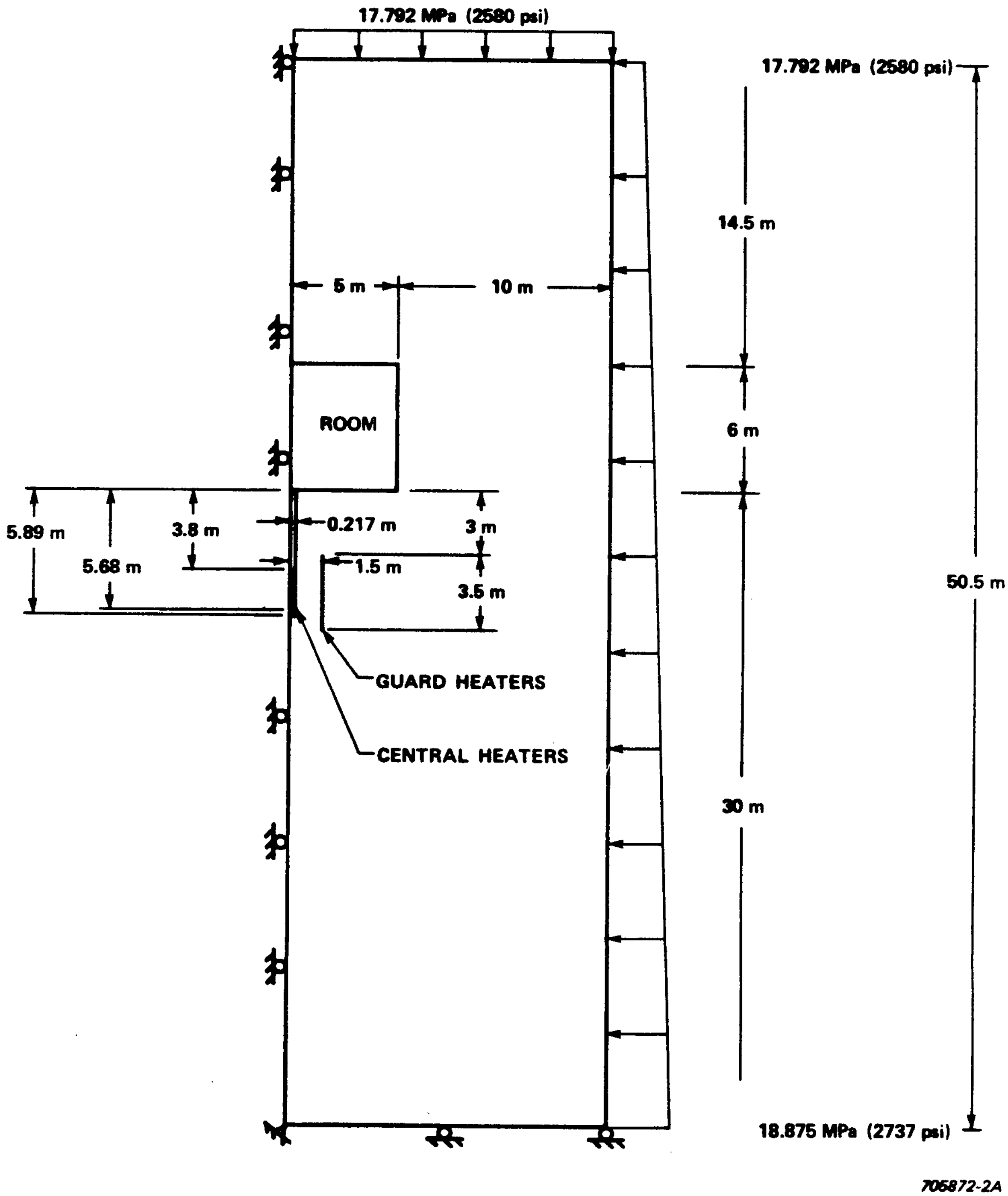

Figure 6-27. Axisymmetric Model Used for Stress Analysis of Brine Migration Test

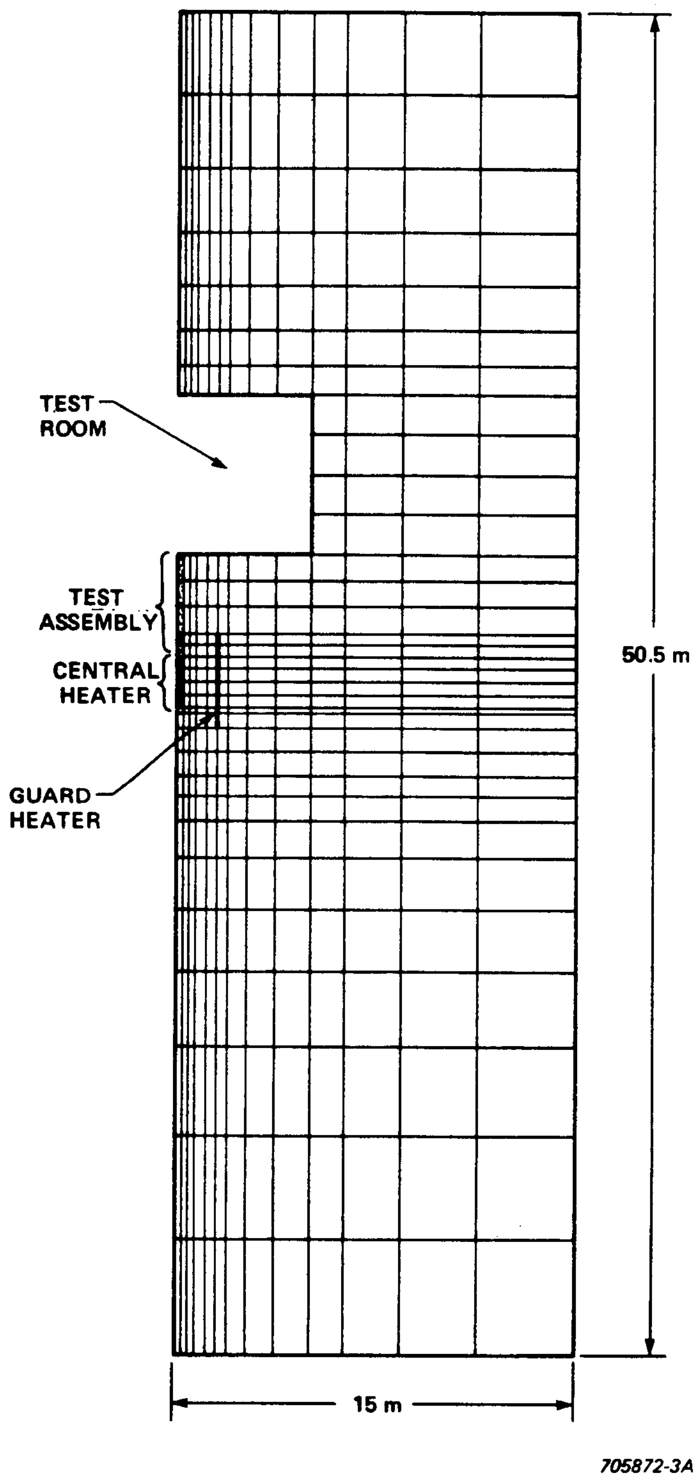

Figure 6-28. Calculational Mesh for Axisymmetric Model for Stress Analysis of Brine Migration Test

Thermal effects are simulated by inputting the temperatures computed from heat transfer analysis for each element of the model. The analysis with heatup continues for the two-year test duration to Day 1151. From that time to Day 1179, a gradual power shutoff is imposed during cooldown. During the analysis, DAPROK calculates the thermal, elastic, and creep strains.

In addition to the above base case analysis, other cases were run, one assuming no creep and another with twice the salt modulus.

The stress results are of most interest near the test assembly, in the salt of the borehole wall. The stress in the radial, vertical, and hoop directions as a function of depth below the test room is presented in Figures 6-29, 6-30, and 6-31 at various times of interest. Similarly, the shear stress τ_{rv} is presented in Figure 6-32. Variation of radial stress at the heater midplane with radial distance from the main heater is shown in Figure 6-33. The small tensile or compressive vertical stresses shown immediately below the room floor may not be meaningful because they probably represent round-off errors in the calculational routines. Also, stress gradients are usually high in the neighborhood of a free boundary so that a finer finite element mesh may be required which is impractical for the present analyses. The actual stresses are near zero.

Figure 6-34 shows the maximum shear and the mobilized friction angle, Φ (defined as the arctangent of maximum shear stress divided by the average normal stress) as a function of depth near the main heater. The plot of mobilized friction angle was developed so that the potential for sliding along any discontinuities which may exist in the host rock salt can be evaluated. A larger value indicates a higher tendency to slip. This is considered to be necessary because of characteristic uncertainty in the homogeneity of the salt and the potential for the creation of cracks during heat up and test operations. The results are presented for the time when the radial stress is maximum on Day 431.5.

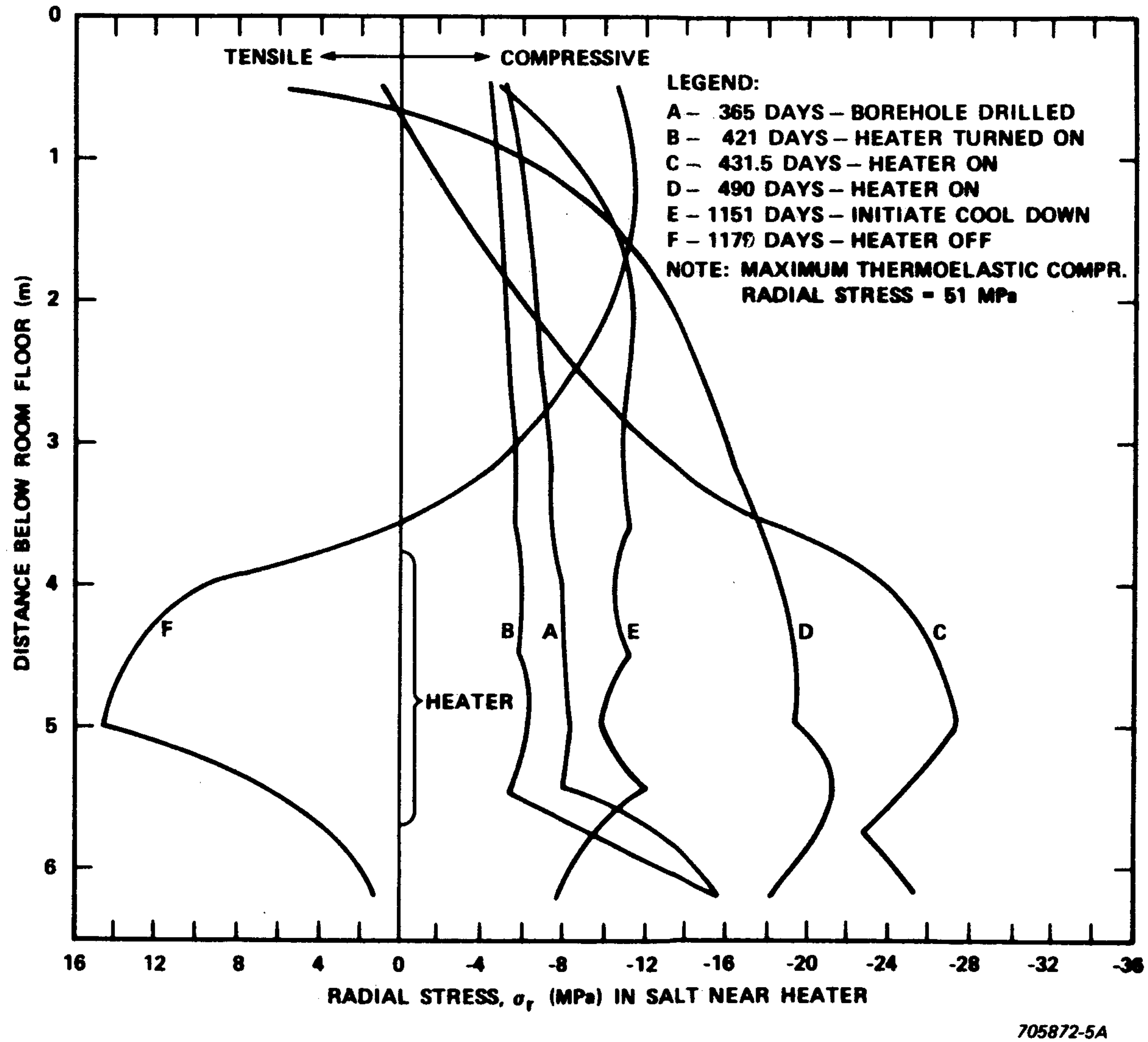

Figure 6-29. Radial Stress in Salt Near Borehole Wall at Various Times

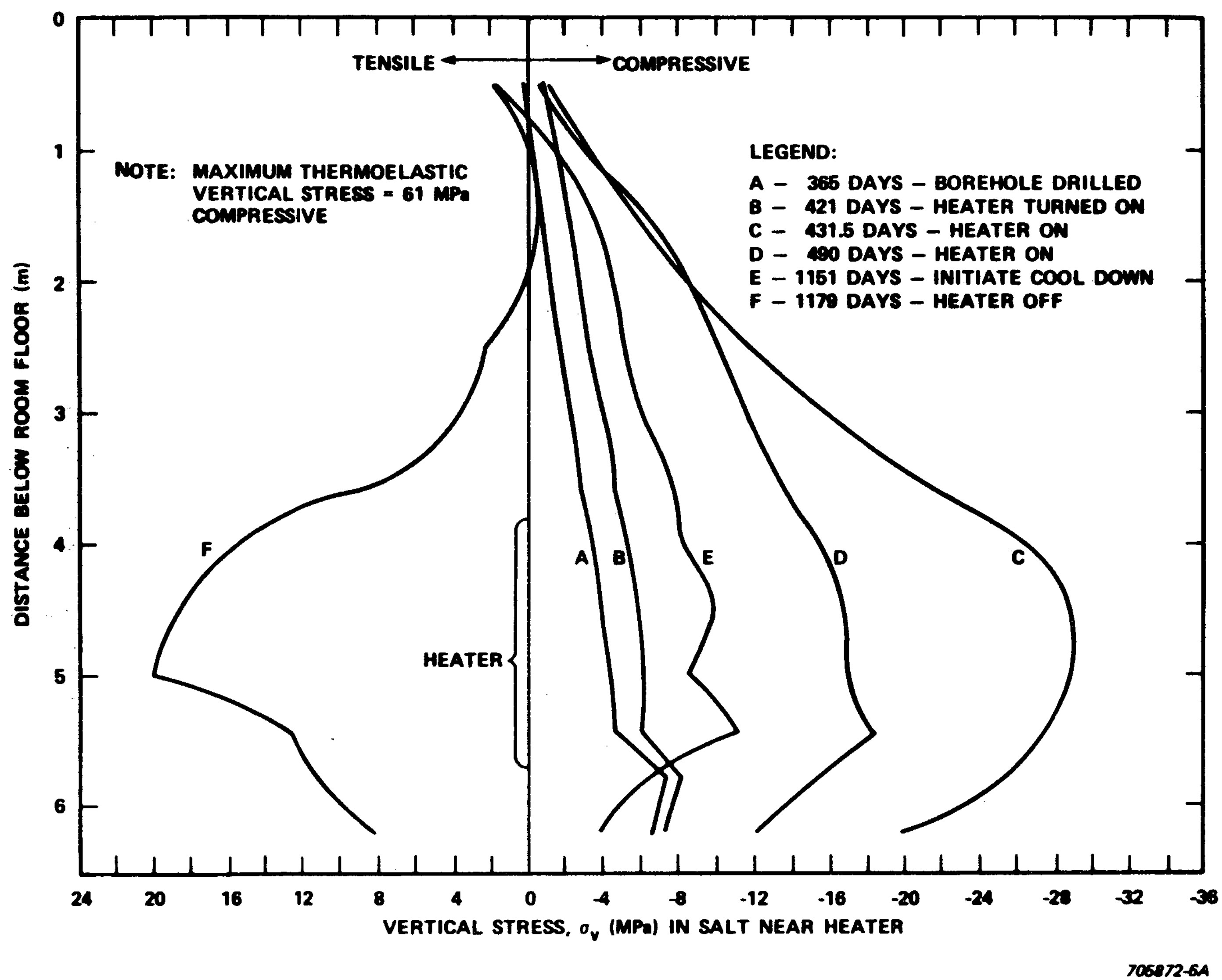

Figure 6-30. Vertical Stress in Salt Near Borehole Wall at Various Times

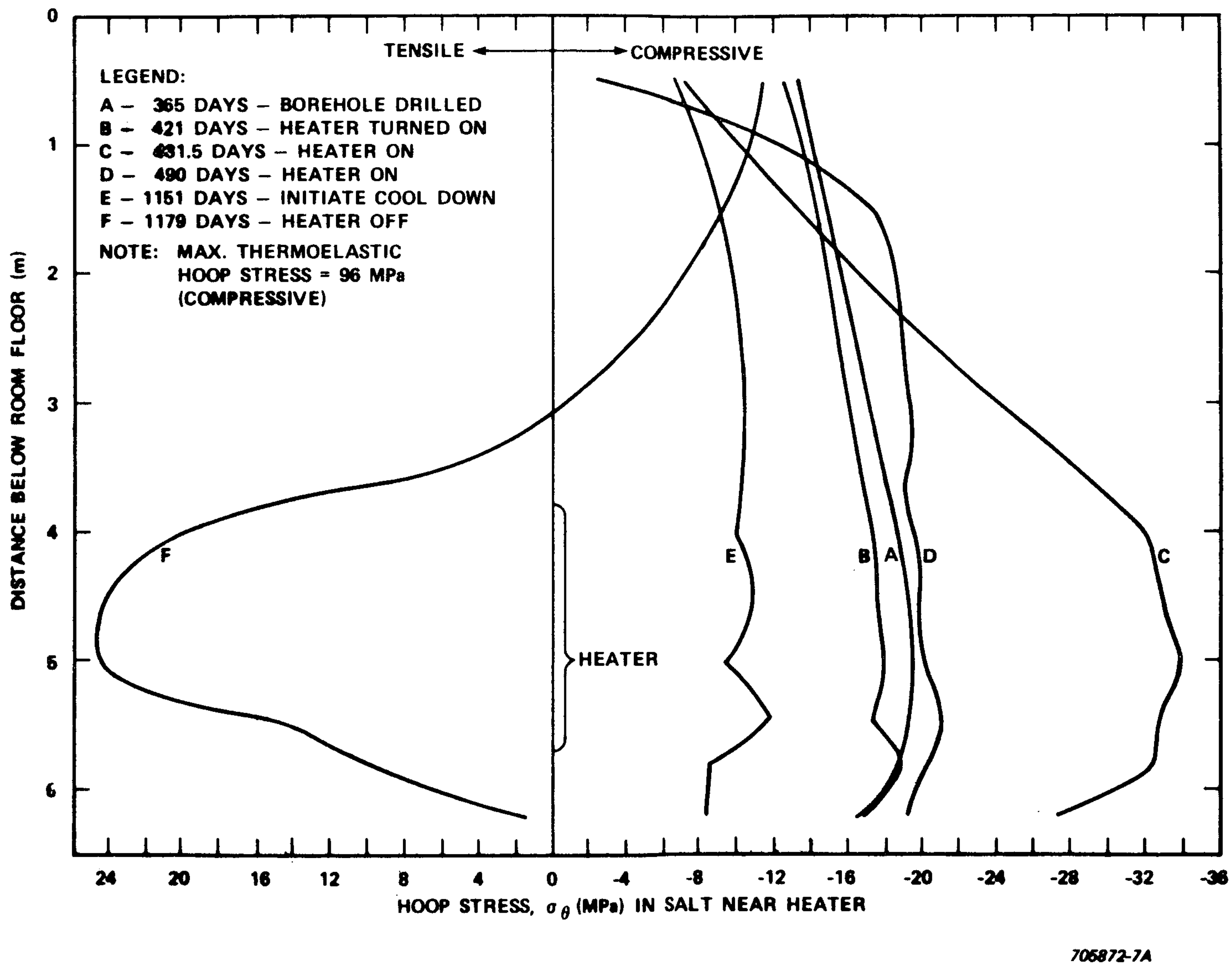

Figure 6-31. Hoop Stress in Salt Near Borehole Wall at Various Times

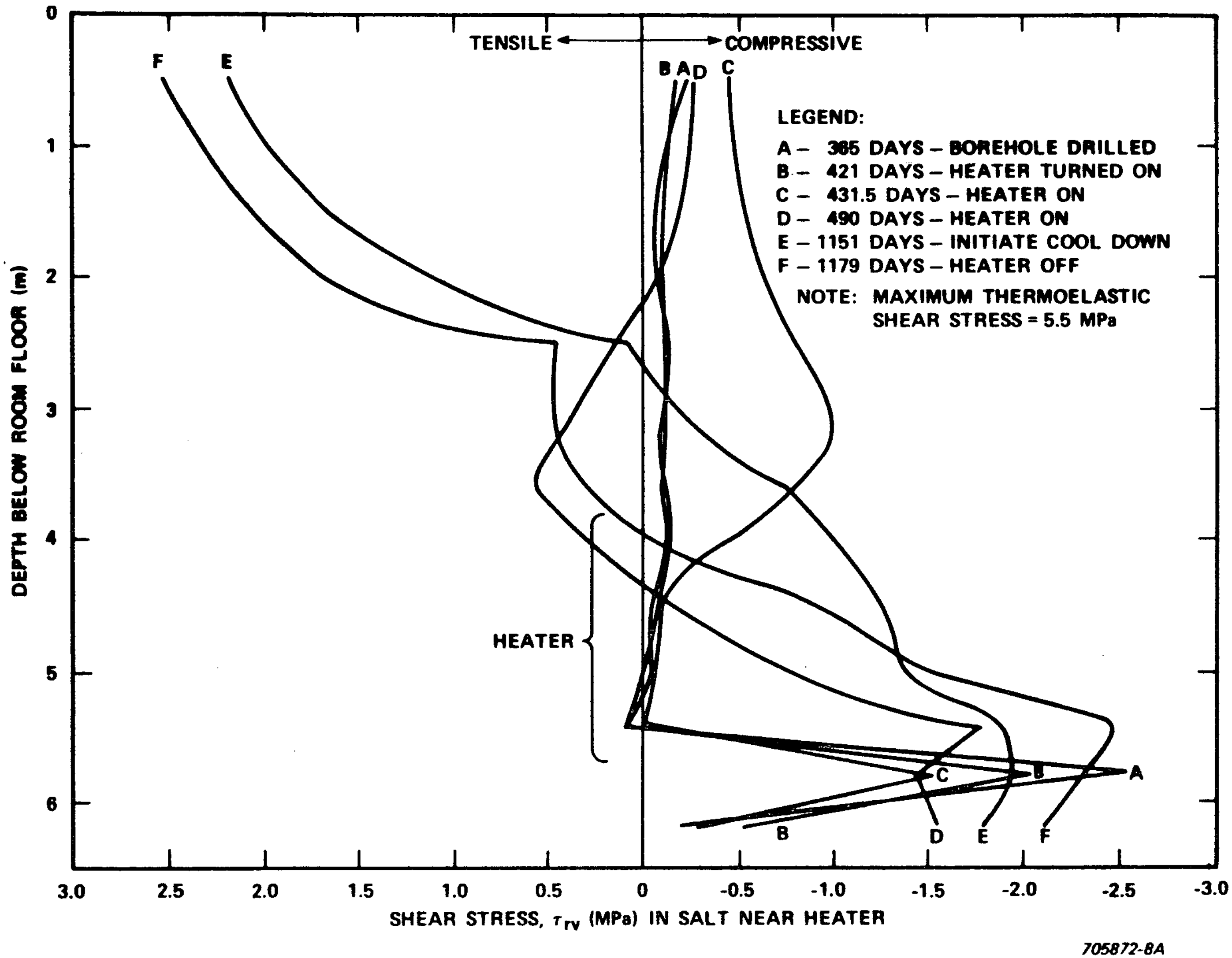

Figure 6-32. Shear Stress in Salt Near Borehole Wall at Various Times

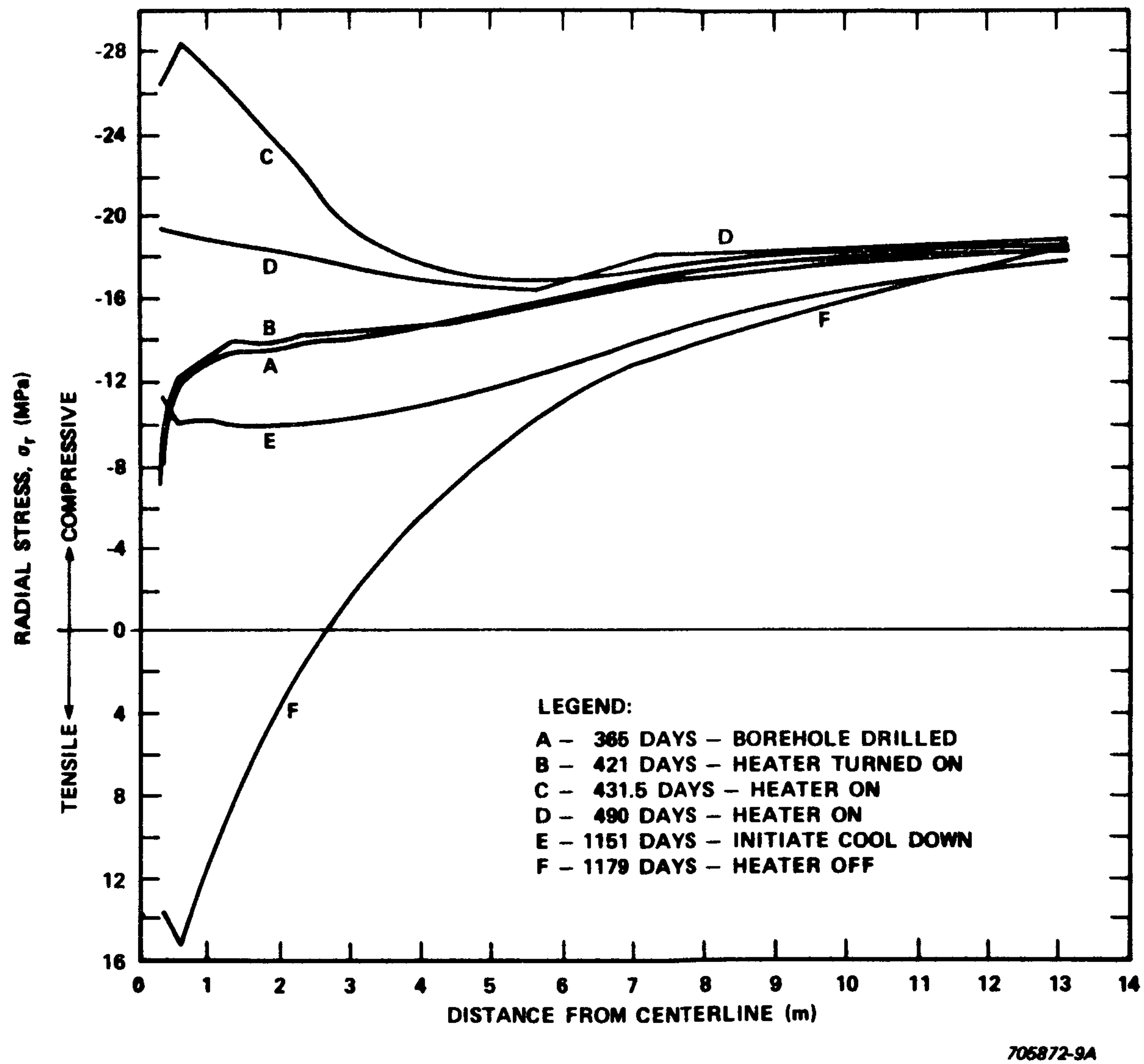

Figure 6-33. Radial Stress in Salt at Heater Midline at Various Times

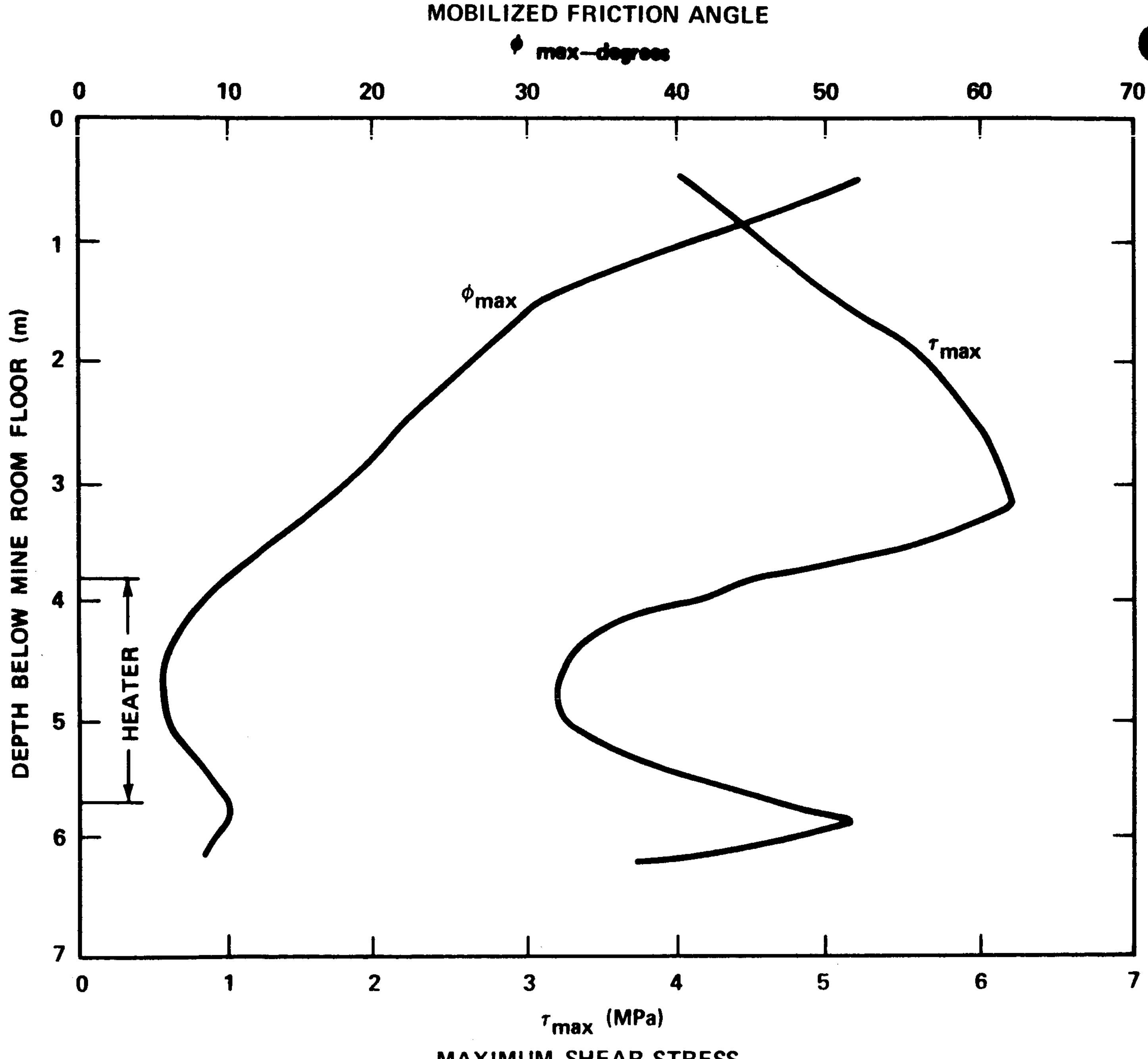

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Figure 6-34. Maximum Shear Stress and Mobilized Friction Angle in Salt Near Borehole Wall at 431.5 Days

Figure 6-35 presents the zone of less than 0.7 MPa (100 psi) compressive stress below the test room floor. This zone encompasses all time points during the first 1,151 days (that is, before cooldown). If, for any element, any one of the three principal stresses is less than 0.7 MPa, that element is included in the zone of small compression in Figure 6-35.

Figure 6-36 shows the zone below the test room floor where tensile stresses occur during the cooldown period. These tensile stresses are fictitious and a direct result of assuming the salt to be a homogeneous isotropic material.

Because the salt cannot carry significant amounts of tension, the tensile stress will be relieved by fracturing. The actual fractured zone will extend beyond that shown in Figure 6-36.

Figure 6-37 illustrates that the maximum radial stress would increase by 40% due to a twofold increase in the elastic modulus of salt.

6.9.4 Discussion of Results and Recommendations

Radial Stress on the Main Heater

From Figure 6-29, the maximum radial stress on the heater is 27 MPa (3,900 psi). As the heater is turned on, the compressive stress increases rapidly. Simultaneously, salt creeps to relax the stress. The increasing salt temperature increases the relaxation rate. If the heatup rate is significantly rapid such that sufficient time is not available for creep relaxation, the stresses will build up to a high level. However, after about 10 days of heating, the creep relaxation overtakes the thermoelastic stress buildup such that beyond that period the radial stress at the heater borehole wall decreases. The maximum estimated radial stress is 27 MPa whereas it would be 51 MPa (7400 psi) if only elastic behavior of the salt is considered; indicating that the creep provides significant relief from compressive stress.

The radial stress continues to drop over the two-year heating period to a level of 12 MPa (1740 psi) (compared to 18 MPa (2600 psi) lithostatic stress at the model boundary).

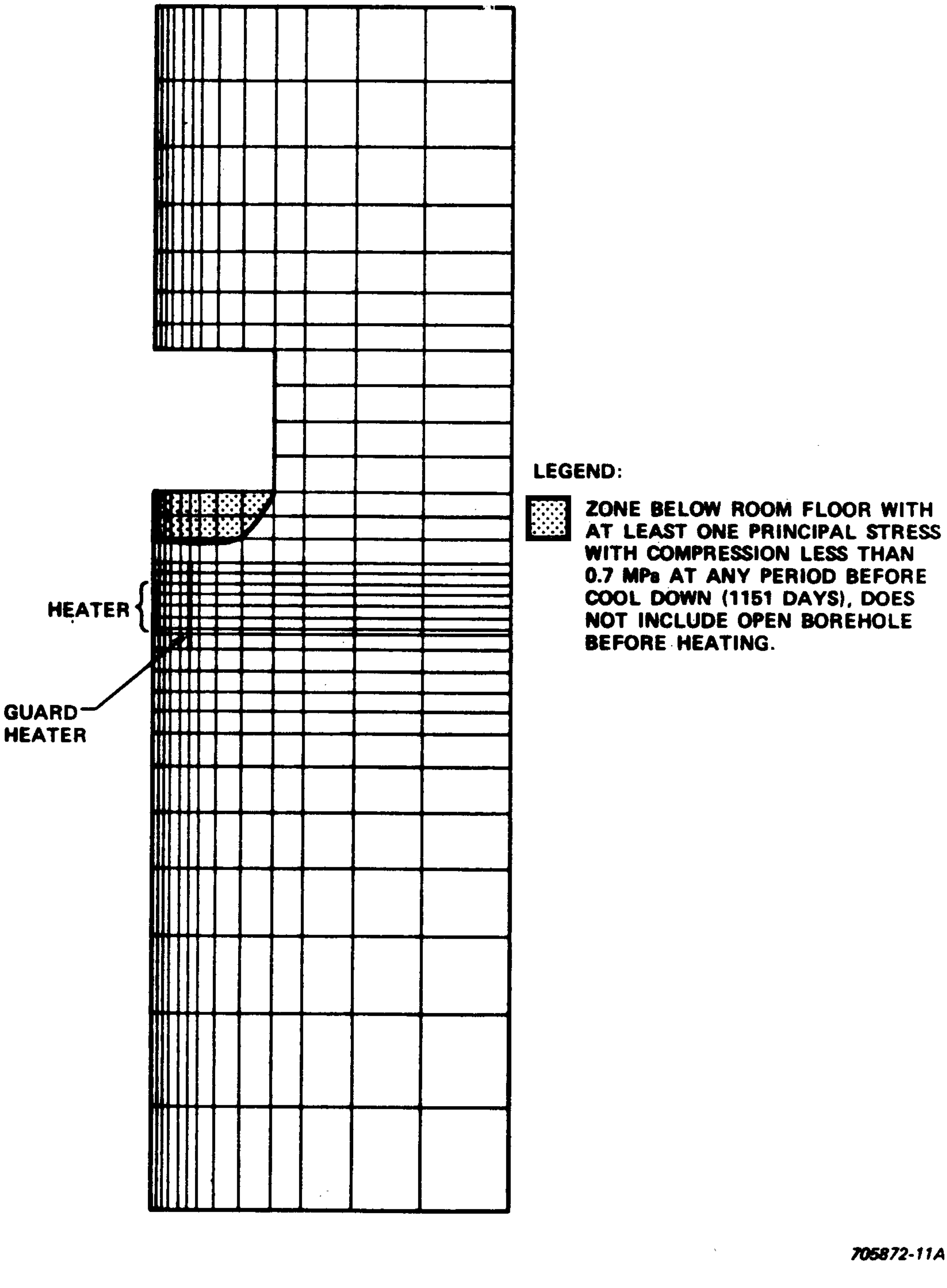

Figure 6-35. Zone of Potential Salt Cracking During Heating Phase

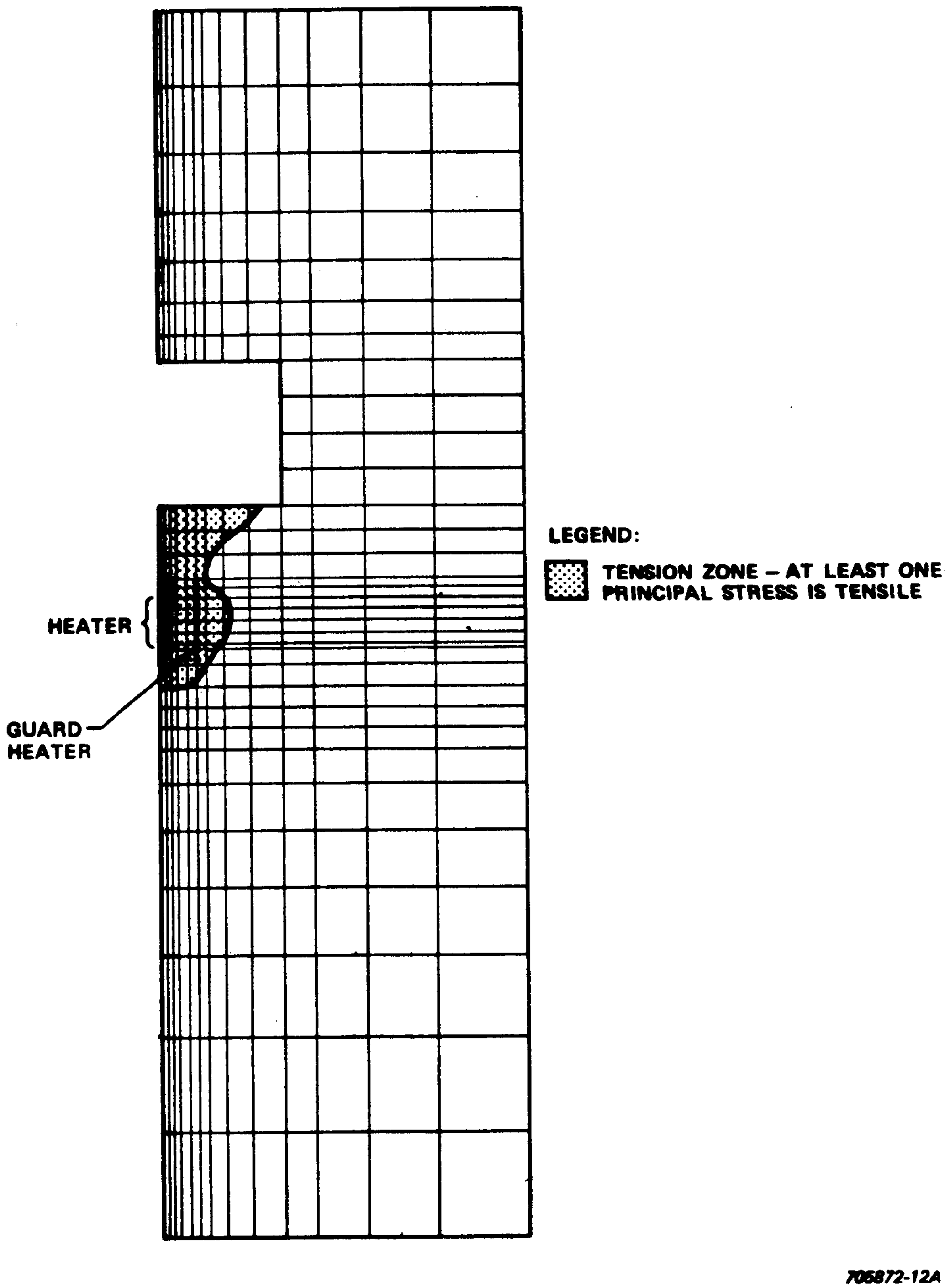

Figure 6-36. Zone of Potential Salt Cracking Below the Room Floor During Cooldown Phase

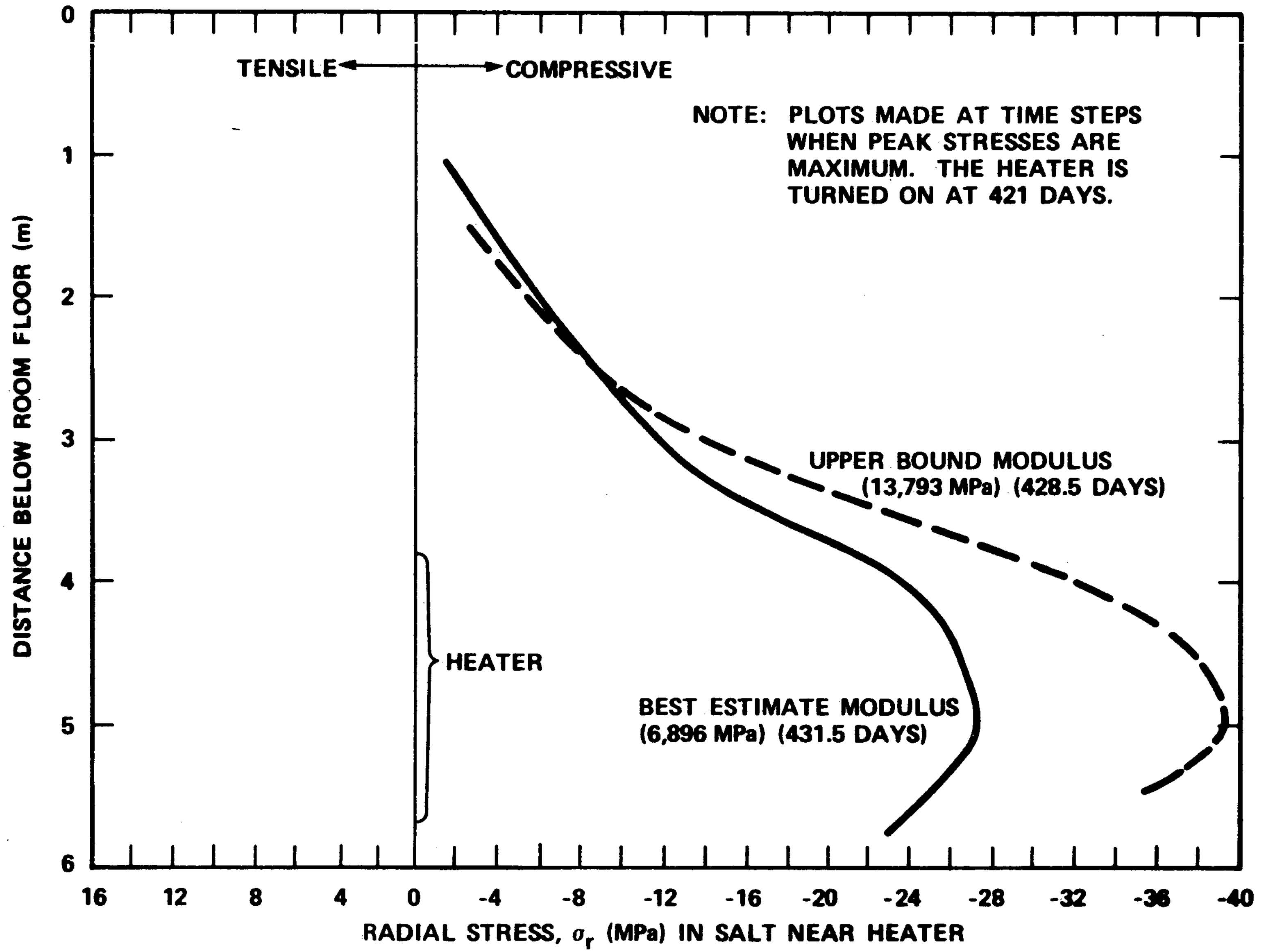

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Figure 6-37. Effect of Variation in Elastic Modulus on Maximum Radial Stress in Salt Near Heater

Possibility of Fracture Development

Fractures may develop and propagate in areas where tensile stresses exist or where maximum shear stresses are very high relative to corresponding normal stresses. A minimum compressive stress of 0.7 MPa (100 psi) is selected as a cutoff for the tension zone because numerical errors in modeling may predict small compressive stress when in fact tensile stress should be predicted. Also, gas pressure in the heater zone could be as high as 0.5 MPa (70 psi) gage, which could result in opening fractures if the compressive stress across the joint were less than the gas pressure.

During the heatup phase, the principal stresses are mostly compressive in the entire body of the salt. The zone below the room floor with mimimum compressive principal stress of 0.7 MPa is shown in Figures 6-35. This zone is mainly immediately below the test room floor. It does not extend to the depth of the seal but is within approximately one meter of it. Hence, although the current test zone is out of tensile stress zone, it may be desireable to move it to an even deeper location.

The possibility of joint movement due to high shear stress is evaluated in Figure 6-34. Salt at 150 degrees Centigrade is known to have about 11 MPa (1600 psi) cohesion with a small angle of friction (Wallner, 1979). At room temperature, salt exhibits an angle of friction of 45 degrees (with small cohesion) up to a normal stress near 25 MPa (3600 psi) and a cohesion of 25 MPa with a small angle of friction beyond that. Figure 6-34 shows that the maximum Φ loading (that is, arctangent of maximum shear stress divided by the normal stress on the maximum shear surface) in the heater zone being near 17 degrees and the maximum shear stress is about 6 MPa (870 psi). The Φ loading and maximum shear loading drop rapidly as one moves away from the heater borehole wall. Thus, the likelihood of shear-induced fracture propagation in the borehole wall and in the heater zone (depth greater than 3.0 meters) is not significant.

The Φ loading in salt near the room floor rises to near 50 degrees, thus suggesting the possibility of shear induced fracture development (in addition to tension induced fractures discussed earlier) immediately below the test room floor.

The shear stress between the heater sleeve and borehole wall is significant (Figure 6-32) and some slip may occur between seal and salt if the seal is not sufficiently adhesive (see following discussion on Impact on Sealing Design).

Axial Loads on Test Assembly

There is a tendency for salt to move toward the free surface of the mine floor due to the influence of lithostatic stress and thermal expansion and creep. The salt adjacent to the top of the test assembly creeps into the room more than the salt at the bottom of the assembly by 4 cm (1.6 in) over the two year test duration, Figure 6-38. Since, for this analysis, the test assembly is assumed to move with the salt wall, the test assembly is stretched by this amount over its 5 meter length. This translates into an axial strain in the test assembly sleeve of about 1 percent, a clearly unacceptable strain level. This high stress is calculated because the cross sectional area of the test assembly is very much less than that of the salt, even though its Young's Modulus is 30 times higher, so the salt "drags" the test assembly along with itself.

The 1 percent strain is much greater than the 0.1 percent elastic limit of the test assembly materials. The assembly does have the capacity to undergo this plastic strain, but it is not normally desirable to design equipment to operate in the plastic range. It is less desirable in this instance due to the simultaneous imposition of compressive radial stress on the assembly which would tend to crush the assembly.

The assumption of no slip on the assembly walls should be examined. As shown on Figure 6-34, the Φ loading along the assembly is relatively low, indicating little tendency to slip. Along the region with alumina beads where the friction may be least, the Φ loading is particularly low (likely due to the increased creep rate from the higher temperatures here). Thus, the assumption of no slip may not be unrealistically conservative.

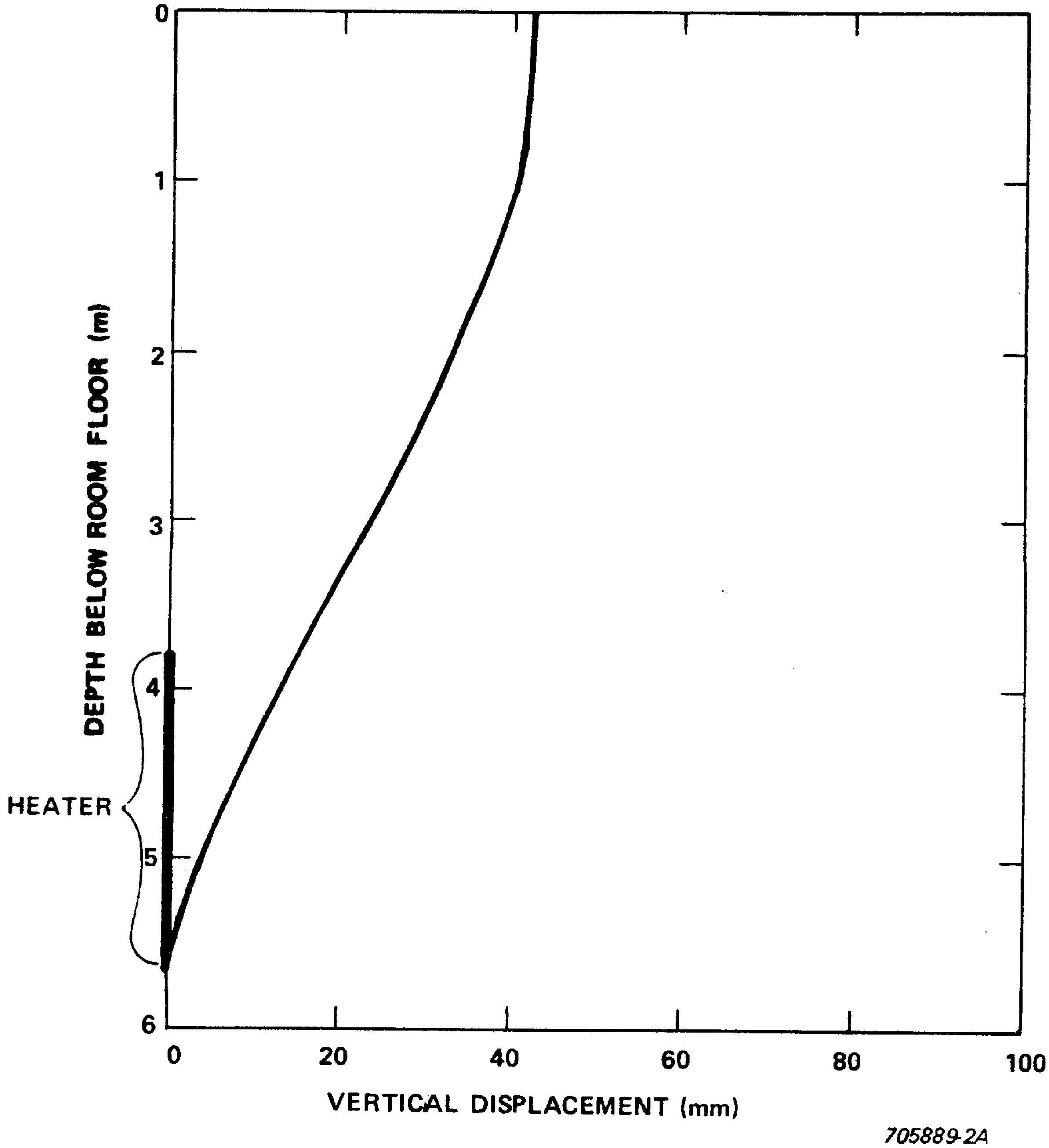


Figure 6-38. Relative Vertical Displacement of Salt Adjacent to the Central Heater Between 421 and 1151 Days

Two items may be beneficial. The first is that there is an initial gap of about 1 cm (3/8 in.) between the upper casing and the borehole wall above the seal. This gap may not close for a considerable time since the temperatures are considerably reduced in this region and so the creep rate is slower. The second is that examination of the history of Φ loading may reveal times when slip may occur more easily along the assembly. In addition, a change to the heating sequence could provide some relief. These items may reduce the amount of axial stretching of the assembly to manageable proportions. If these are not sufficient, changes to the design of the assembly will be required to accommodate axial elongation, such as a lubricated telescoping outer sleeve, for instance.

In any event, the axial stretching of the assembly will require further examination, both analytically and design-wise. It is further noted that, although the brine migration test design is somewhat different from potential waste disposal packages, there is sufficient similarity to indicate that similar evaluations should be conducted on these designs.

Impact of Cooldown

As indicated in Figure 6-36, and also in Figures 6-29, 6-30, and 6-31, significant tension zones will develop during the cooldown phase. This occurs even when the power has been gradually reduced over a four-week period. As shown in Figure 6-36, the tension zone is extensive and extends beyond the guard heater. This negates the need for further refinement in analysis by using fracture elements since the analysis with these elements which separate in tension will show a fractured zone equal to or greater than that shown in Figure 6-36. The case with sudden power shutdown at the end of the heating testing period has not been analyzed since the sudden shutdown will lead to even more extensive fracturing than that for the four-week cooldown.

The postexperiment diagnostic program and philosophy will be significantly affected by fracturing during cooldown. The salt mechanical characteristics will be changed after the experiment. Thus, all significant mechanical test data must be collected before or during the experiment.

Although not conclusively demonstrated, the development of fracturing during cooldown may be a fundamental phenomenon for heater tests in salt. Extended periods of heat relax the stress in vicinity of the heater to much below its maximum value and significantly below the maximum elastic stress. For instance, in the present analysis, the maximum elastic radial stress is 51 MPa (7400 psi), the actual maximum radial stress considering creep is 27 MPa (3900 psi), and the radial stress relaxes to a value of 12 MPa (1740 psi) at the end of a two-year heating period. During the cooldown, the behavior of salt is nearly elastic since the creep does not have significant time to relax the stress. The stress reduction during cooldown could thus be more than the stress at the beginning of the cooldown, resulting in a net tensile stress. The magnitude of stress reduction is primarily due to temperature changes (independent of the in situ stresses), and therefore it may not be possible to avoid a tension zone by locating the test deeper below the test room floor, particularly if the lithostatic stress at the test level is less than the elastic stress reduction.

Impact of Test Depth Below the Test Room

It appears that a greater test depth below the mine floor would result in a slightly higher maximum radial stress on the heater. However, the possibility of tensile fractures during cooldown would not be significantly reduced by locating the test at a greater depth. Since the lithostatic stress at the 800-meter test level is only 17.9 MPa (2600 psi) and the stress reduction during the cooldown phase is significantly greater (Figures 6-29, 6-30, and 6-31), the tensile fracturing during cooldown may occur at any feasible test depth.

Requirements for Power Continuity

The preceding analysis showed that an approximate three days of partial power reduction will initiate tensile fracturing in the host salt. The exact impact of power loss and regain is dependent on the time sequence and on the time in the test at which the loss takes place. Analysis of various possible scenarios combining the above events is beyond the scope of this work. However, using a criterion that the temperature drop should be less than five degrees Centigrade during any power outage, power should not be out for a period of more than two to four hours.

Impact of Salt Modulus

Figure 6-37 indicates the impact of Young's modulus of salt on radial stresses on the heater. As discussed in Section 6.9.2.4, a modulus value of 6,896 MPa (1.0×10^6 psi) is considered reasonable and the corresponding maximum radial stress is 27 MPa (3900 psi). However, an increase of 100 percent in the modulus value yields an increase of 40 percent in the maximum radial stress to a value of 39 MPa (5,650 psi).

Impact of Gas Pressure

The gas pressure in the test zone will be maintained below 0.5 MPa (70 psig), as established by the test plan. As shown in Figures 6-29, 6-30, and 6-31, the stress in borehole wall salt below the seal is greater than 8 MPa (1200 psi) compressive and, hence, the gas pressure will not initiate tensile fracturing of the salt.

Impact on Sealing Requirements

The seal should be able to withstand the maximum compressive and shear stesses of 6.0 (870 psi) and 3.0 MPa (430 psi), respectively, with adequate margin of safety. Slip or deformation of the seals against the borehole wall is not likely since the ratio of radial compressive stress to shear stress at the seal is relatively low.

The vertical strains and displacements in borehole wall salt are illustrated in Figure 6-39. These strains provide input to seal design as well as the heater assembly design.

Impact on Room Closure

The estimated maximum floor heave and horizontal and vertical room closures from the axisymmetric model are shown in Figure 6-36. The maximum room closure

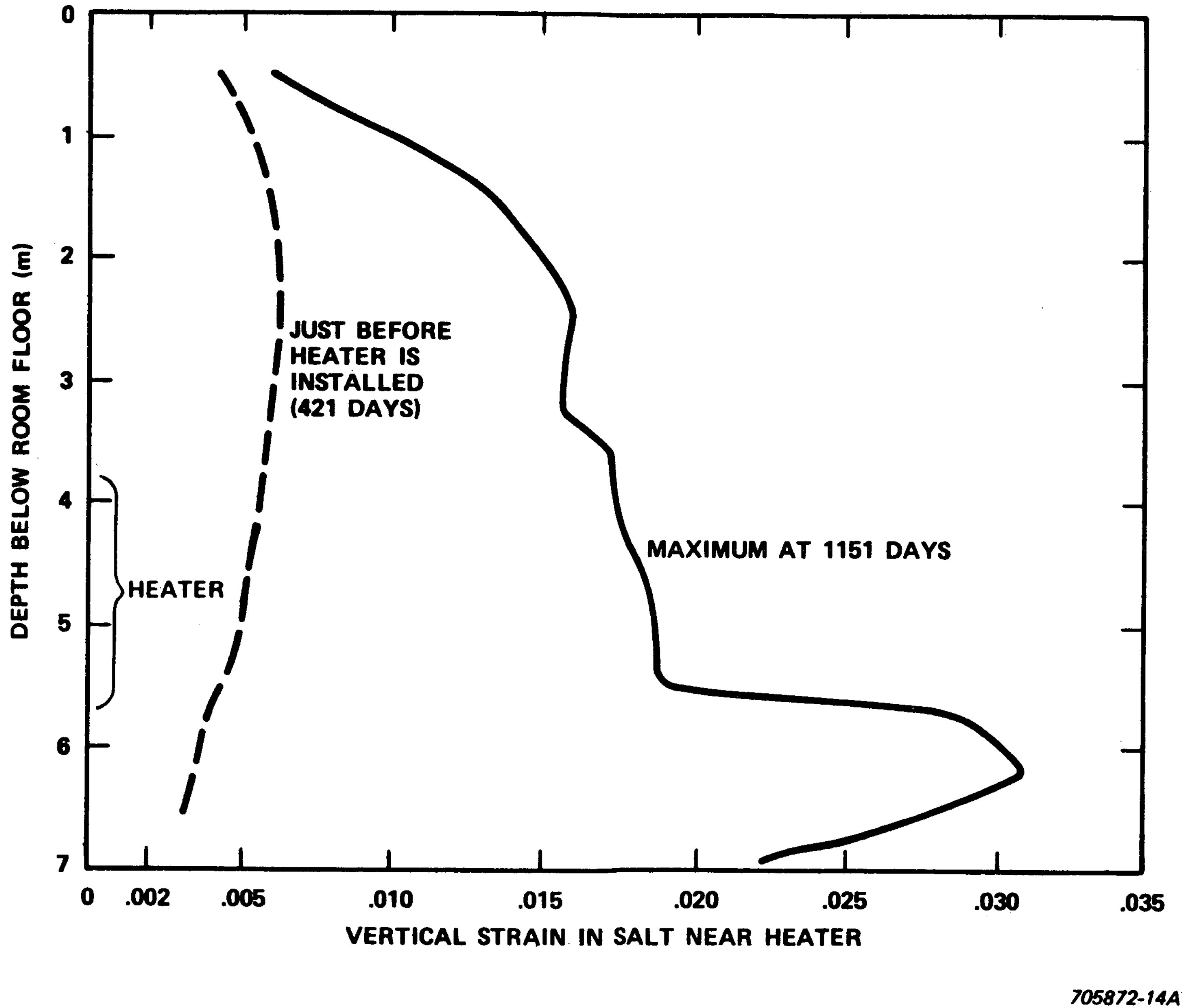


Figure 6-39. Vertical Strain in Salt Near Heater

is about 25 centimeters (10 inches). The actual closure in the test room is likely to be higher than predicted in Figure 6-40.

The axisymmetric model simulates the presence of pillars on all sides of the test zone whereas, in the actual test room, the pillar support is only available on two sides of the test area. In another set of runs made to check the boundary conditions, it was observed that, without the heater, the vertical room closure over a one-year period was 2.6 times as much in the plane strain model as in the axisymmetric model. If this ratio is also valid during the heating phase, unacceptable room closures may occur. Thus, this problem should be further evaluated as a part of the test room design. (Another possibility is that the creep model predicts too high of a strain rate and thus the room closures might be over predicted.)

Impact of Parallel Test Gallery

To evaluate the impact of a parallel test gallary, vertical plane strain creep models were developed with two different pillar widths of 12 and 20 meters. These analyses did not include the presence of heaters in the test zone. The results from the analyses are summarized in Figure 6-41.

If the test rooms are far enough apart, the presence of one room does not affect the symmetry of stress conditions around the other room. It is evident from Figure 6-37 that this symmetry is essentially maintained when the pillar between the test rooms is 20 meters wide but not when the pillar width is only 12 meters wide.

Since the widths of S and U salts available in the test area are not sufficient to allow a 20-meter pillar between the two test drifts, it is strongly suggested to use a Z-shaped test room configuration so that the two test drifts are not next to each other.

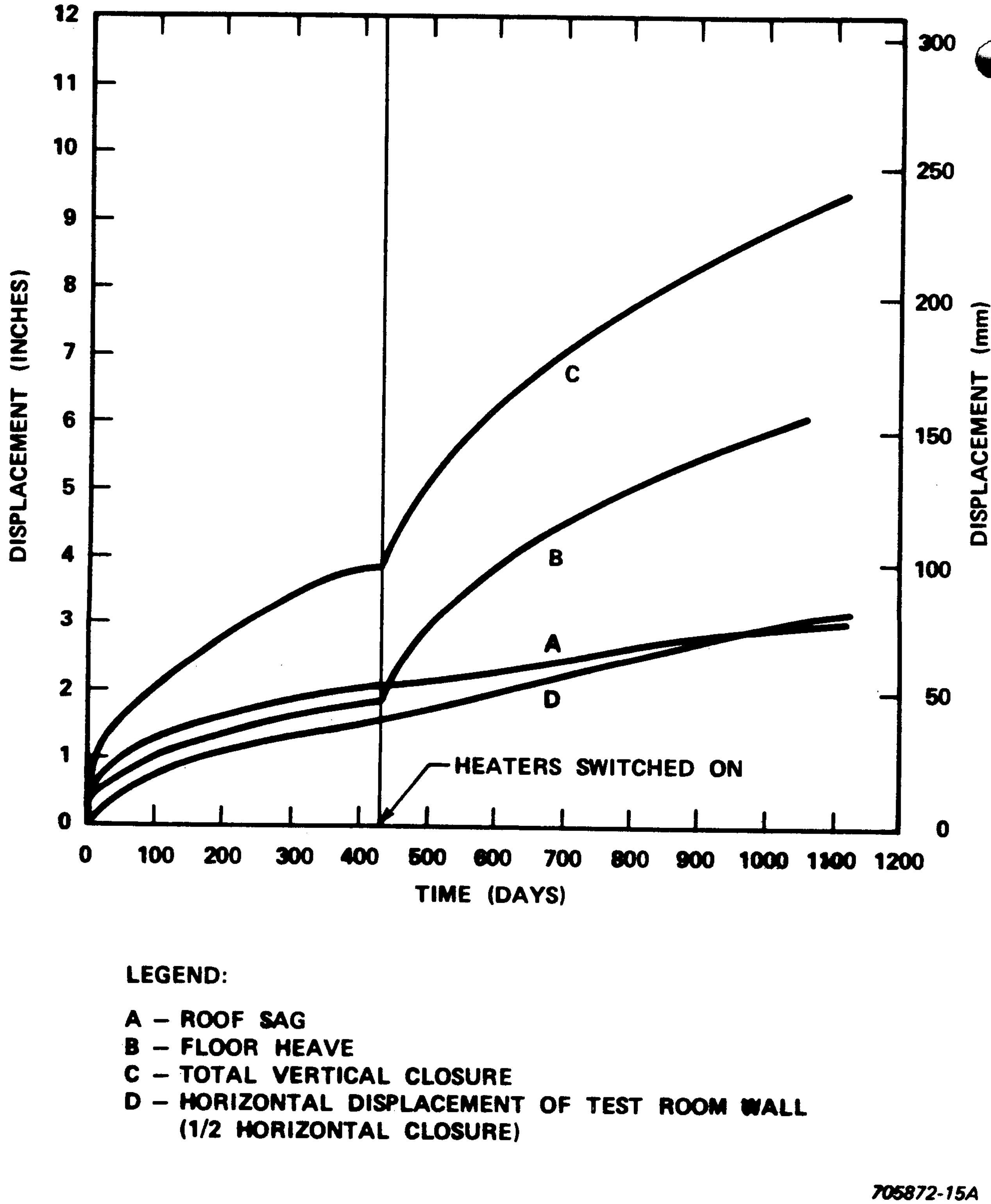
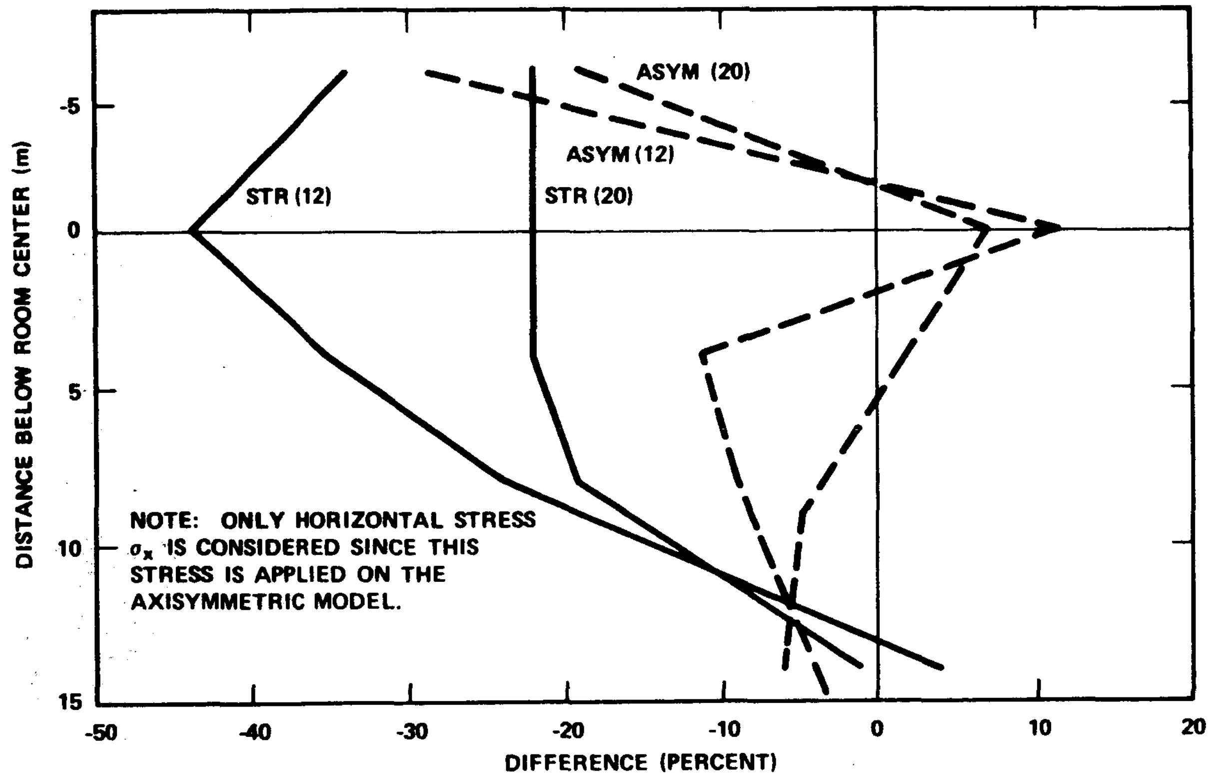


Figure 6-40. Calculated Closure of Room Above Test Site



LEGEND:

STR (12), STR (20): DIFFERENCE BETWEEN LITHOSTATIC STRESS AND σ_x AT PILLAR MIDPLANE, FOR 12 AND 20 METER PILLARS.

ASYM (12), ASYM (20): DIFFERENCE BETWEEN σ_x AT PILLAR MIDPLAND AND σ_x AT THE SAME DISTANCE OUTSIDE THE ROOM, FOR 12 AND 20 METER PILLARS.

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Figure 6-41. Variations in Stress due to Interaction Between Adjacent Test Rooms

Impact of Modeling Assumptions

The basic modeling assumptions requiring evaluation are (a) size of the model, (b) fineness of the mesh, and (c) time step increments. Evaluation of these assumptions indicates that they are appropriate.

Study of one-layer axisymmetric models considering thermal and creep effects indicates that (a) extending the model from a 15- to a 25-meter radius does not significantly change (less than 10 percent) the stress conditions near the heater borehole and (b) having twice as fine a mesh in the radial direction does not affect the stresses by more than 10 percent.

A run of the full axisymmetric model throught the heatup phase with time step increments half as small as in the original run did not affect the stresses near the borehole by more than 10 percent.

6.9.5 Concluding Remarks

The results presented here are quite revealing and significant to the design of test hardware, philosophy, and procedure. However, these results must be used with engineering caution and conservatism due to several potential uncertainties. Two factors with potentially significant effects on the results presented are (a) the current state of knowledge of elastic, thermal, and creep properties of salt and (b) possibility of different interface conditions at the heater borehole than those analyzed; i.e., slip or gaps.

The in situ elastic modulus, the creep behavior, and the creep behavior of natural salt have much higher variability than man-made materials such as steel. Further, the phenomenon of creep is not well understood under complex loading conditions. The creep of salt during the unloading phase such as during the cooldown phase has not been fully evaluated and may possibly be different than the creep during the loading phase.

The initial conditions such as a presence of gap (or prestress) between heater and the borehole, manner of packing alumina beads, etc., may significantly affect the maximum loads in the salt.

7.0 EXPECTED RESULTS AND UTILIZATION OF DATA

The collected data from both the Generic Test Design and from the Asse Test Design will be used to help confirm that laboratory derived theories of brine migration are applicable in the field. The important data are the total amount and rate of water collection. Also, the change of amount and distribution of water in the salt at the end of the test will be compared to the start of the test. These data will be compared against the predictions of the brine migration theories, such as those published in Section 6.

Information on the mechanism of brine migration can be determined from the results of a single test by observing the shape of the water collection rate curve. The liquid inclusion migration model predicts much less falloff in water collection rate than does the vapor migration model. Also, the radial distribution of the remaining water in the salt can be related to the mechanism of migration. As shown in Figures 6-15, 6-22, and 6-23, the residual water in the salt is much less near the borehole for the vapor migration mechanism than for the liquid inclusion movement model.

Information on the impact of radiation on brine migration will be obtained by comparison between tests with and without radiation. The effects that may occur are differences in the rate of water production, differences in the total amount of production of water (as a fraction of that available), or differences in transport mechanisms evident in post-test microscopic salt examinations. Variations in initial water content between test sites will be compensated by pre- and post-test evaluations of the salt.

The tests with and without pressurized boreholes will provide an excellent opportunity to differentiate between the liquid inclusion and vapor migration mechanisms. If vapor migration is dominant, then the total water production from the pressurized tests should be very much reduced because the vapor flow rate will be reduced by the higher borehole pressure. On the contrary, liquid inclusion migration should not be affected by the borehole pressure. Thus, the collected water at the end of the test should be very much larger for the unpressurized test if vapor migration is the dominant mechanism while the amount of water collected should be nearly unchanged if liquid inclusion migration is dominant. These data are not so likely to be useful in the Asse test design because the two types of test are conducted in two different types of salt which (at least) differ significantly in total water content.

The series of tests in the generic test design, which vary the borehole wall temperature and temperature gradient, are designed to both further differentiate between the liquid inclusion and vapor migration mechanisms, and also to allow determination of the parameters affecting the rate of movement. This is done by exposing the salt to a variety of conditions and observing the rate of water production. By comparing these rates with computer calculations, the rate parameters can be estimated. Sufficient redundancy is incorporated into the testing to confirm the rate parameters that have been determined.

The data obtained from the tests should be used to verify computer models of brine migration. Then, incorporating parameters appropriate to repository conditions, these models can be used to calculate the amount of water likely to be released from the salt around a waste package. These data can then be used to assist repository and waste package design. In particular, if it can be demonstrated that the amount of water released in a repository is sufficiently low, less conservative assumptions of waste package environment can be utilized, potentially yielding significant reductions in waste disposal costs.

Additional information will be obtained from this test by examining the test hardware and salt from around the test. Unexpected evidence of corrosion of the test materials or changes to the salt physical properties may provide information that can be utilized in the repository design.

8.0 ASSE SITE DESCRIPTION AND CHARACTERIZATION

8.1 GENERAL DATA

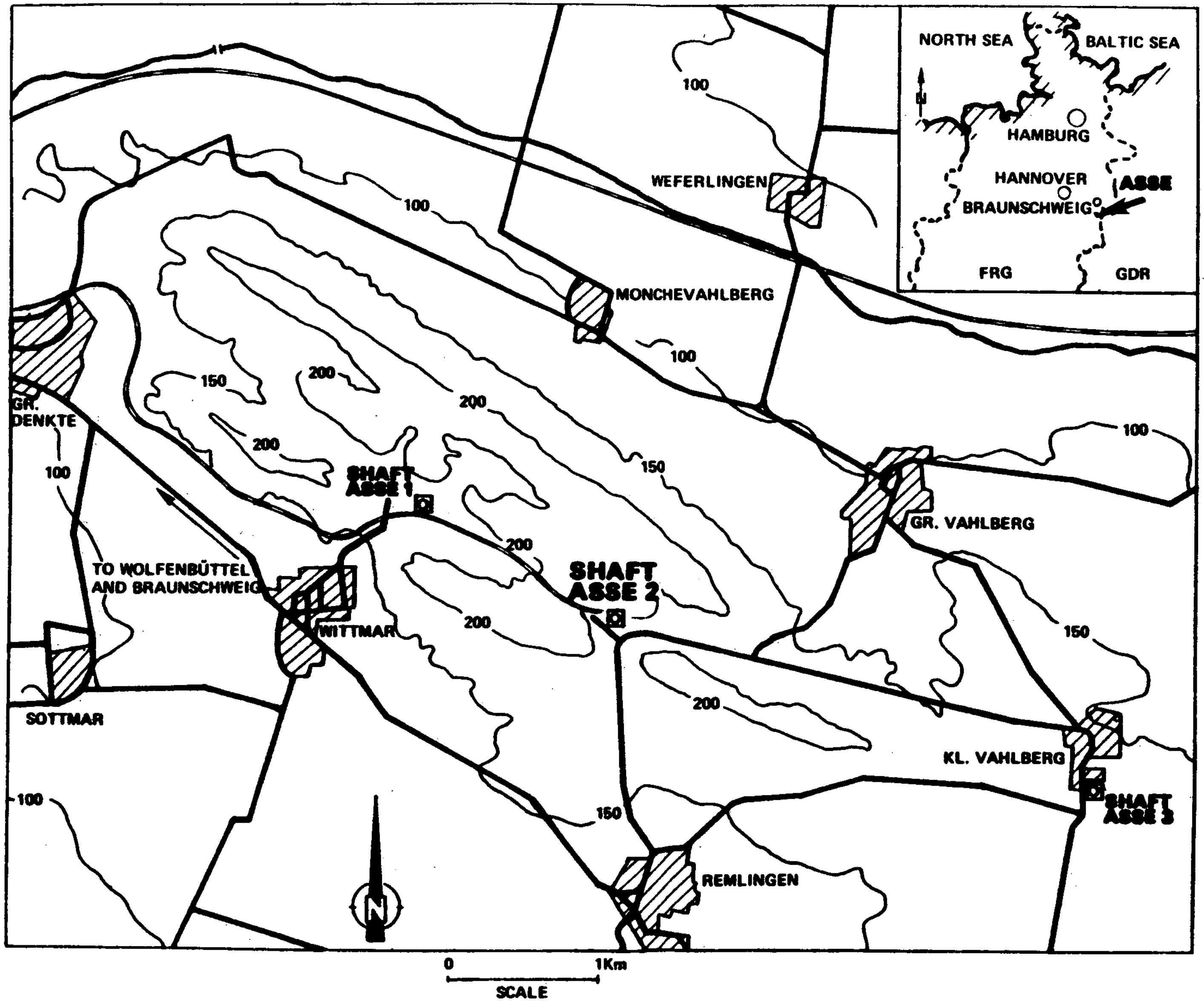
8.1.1 Regional and Mine Geology

The beginning of exploitation of the Asse region dates back to late 19th Century. Since then, a wealth of data has been gathered which appears in numerous published and unpublished reports.

The location of the Asse Salt Mine is shown on Figure 8-1. The mine is situated 1.5 kilometers north of the village of Remlingen, 10 kilometers southeast of the county town of Wolfenbüttel and about 18 kilometers southeast from Braunschweig. The Wolfenbüttel County is part of the District of Braunschweig within the Federal State of Lower Saxony. The Asse Mine can be reached by road or by a railway spur.

The Asse is a chain of hills about eight kilometers long with a maximum width of four kilometers. The hills are the topographic expression of a salt dome which has been diapirically intruded into the "Buntsandstein" and "Muschelkalk" formations (Figure 8-2). The salt rocks in the core of the anticline were formed by evaporation of the ocean 250 to 220 million years ago in the Permian (Zechstein Series). The initially horizontal strata were folded diapirically to form the present Asse anticline about 110 million years ago, in the Cretaceous period.

The southern flank is partially overturned, whereas the strata at the northern flank at first dip 40 degrees and then flatten out to the north. The northern flank has been lifted up 400 to 500 m more than the southern flank. The oldest outcropping stratum to the south is the Lower Muschelkalk (mu) and to the north, the even older Lower Buntsandstein (su).



LEGEND:
HIGHWAY AND/OR LOCAL ROAD
RAILROAD
MINE SHAFT
200 GROUND SURFACE CONTOUR LINE (METERS ABOVE MEAN SEA LEVEL)

Figure 8-1. Asse Mine Location

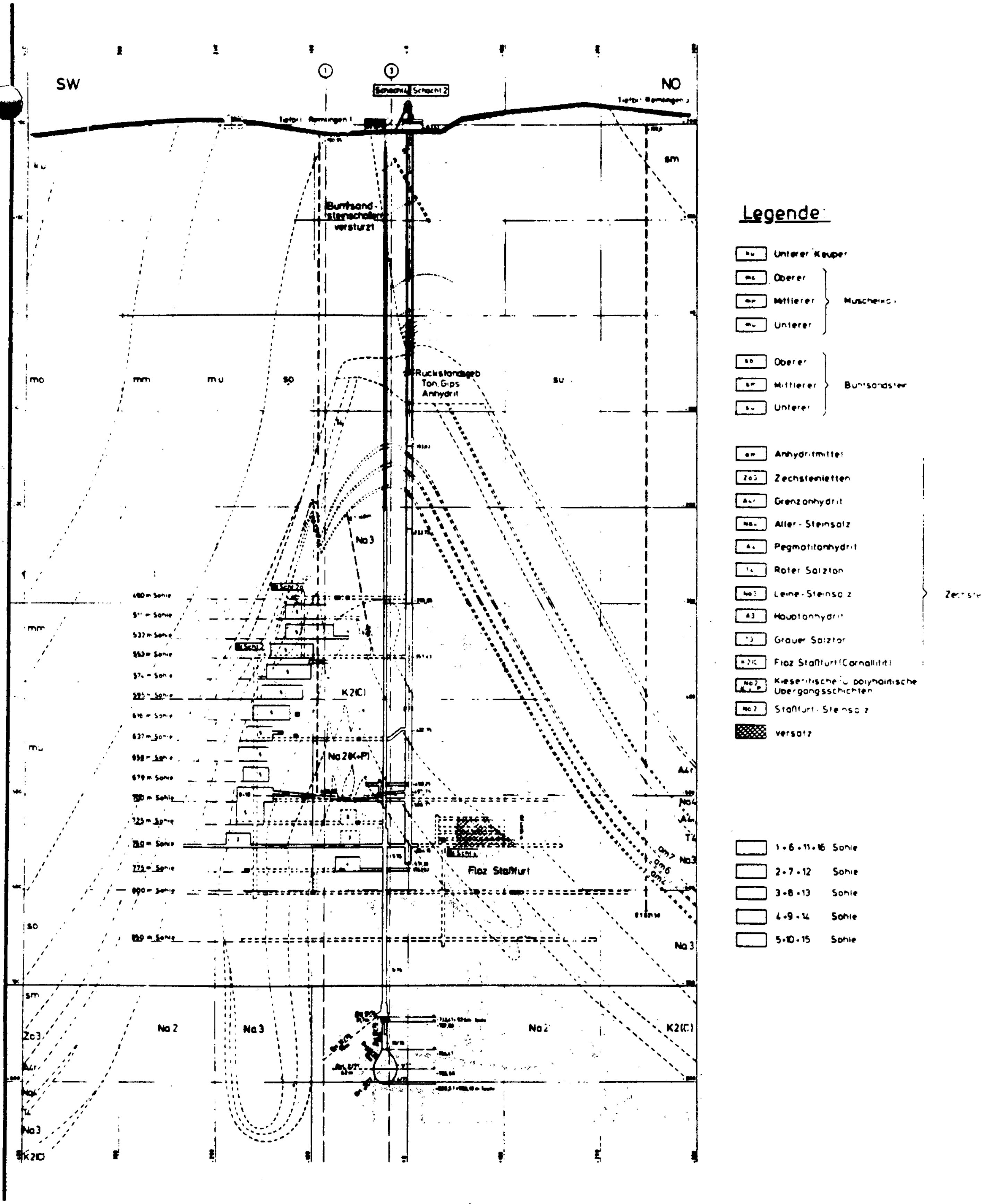


Figure 8-2. Asse II Mine Cross Section

The so-called collapsed rocks between these two strata to a depth of 240 m consist of seven big tilted-fault blocks of Lower Buntsandstein (su). The caprocks mantling the dome at a depth of 270 m consist mainly of clay/siltstone and anhydrite.

The major salt deposits in the anticline can be divided into a brown and white Younger Halite (Na 3) (see Table 8-1) formation underlain by a red Stassfurt Carnallite (K2[C]) zone and separated from the white Older Halite (Na 2) formations forming the core of the dome. On both flanks of the anticline, there exist strata of the youngest Aller-Series (T4, A4, Na4, A4r, and Z03).

The salt anticline is covered with strata which seal it from groundwater. Its existence in its present form over a period of more than 100 million years proves that solution of salt has occurred only on an extremely small scale. In order to get more data on the groundwater conditions, an extensive hydrogeological investigative program is presently being performed around the entire range of Asse hills. Some of the boreholes encountered isolated appearances of saturated brines or gas or both; mostly in strata containing clay layers.

Because of the chemistry of the salt deposits, the presence of hydrated minerals and the background natural mine temperature of 36 degrees Centigrade, there is a small occurrence of $MgCl_2$ saturated brine in the mine. The carnallite zone contains 52 percent carnallite, 30 percent halite, and 14 percent kieserite. At temperatures above 110 degrees Centigrade, water of hydration is released and above 65 degrees Centigrade, gaseous hydrochloric acid is produced. Therefore, zones containing significant quantities of carnallite should be avoided in the test field.

8.1.2 Mining History

The first shaft, Asse 1*, was sunk to a depth of 375 m in 1899 and 1900. Potash salt was mined in the Asse I mine on three levels just beneath the surface in this uppermost region where the sealing strata were missing, and by ignorance of the hydrological menace in doing so, an inflow of water occurred in 1906 causing flooding of the underground workings and abandonment of the first mine. Therefore, a new shaft, Asse 2, was sunk at a distance of about 1,400 m southeast from Asse 1 to a depth of 765 m from 1906 to 1908.

In order to provide the Asse Salt Mine with two separate shafts, sinking of the shaft Asse 3 started in 1911 at a distance of about 3,400 m southeast of shaft Asse 2. This 725 m deep shaft was not completed until 1921, because of unexpected difficulties during the sinking and delays caused by World War I. However, the extraction in the Asse III mine never started and the mine was shut down in 1925. Afterwards, surface water accumulated in the shaft (due to a lack of maintenance) and today stands about 42 m below the shaft cap.

The principal mining activities in Asse dome were undertaken in the Asse II mine served by shaft Asse 2. At first (starting in 1908), only potash salt was mined in the Stassfurt bed K2(C) very deep in the core of the anticline. Thus, any hydrological menace was avoided. In 1916, the extraction of rock salt was also started. This extraction was always done with the necessary safety to prevent any water inflow. The mining of potash salt was abandoned at the end of 1925 due to a major crisis of the German potash industry after World War I. A total of 26 rooms were created in the northern flank of the Asse anticline. All of these rooms were backfilled, however, and so they cannot be entered today.

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*Arabic numerals refer to shaft identification while Roman numerals refer to mines. For example, shafts Asse 2 and Asse 4 provide access to the Asse II mine.

Later, only rock salt was mined until March 31, 1964, when mining terminated because of economical reasons. Since then, no commercial mining has been done in the Asse region.

A total of 131 rooms (3.6 million m^3) on 13 different levels were mined in the Younger Halite (Na 3) between the 750 m and 490 m levels, by improper mining spiral roadways progressing upwards along the salt anticline. A normal room was 40 to 60 m long, 20 to 40 m wide, and 10 to 15 m high. Between rooms on one level, pillars were left with a width of 12.5 m. Between rooms situated one above the other, safety roofs were left with a thickness of at least 6 m.

Salt was also mined in the Older Halite (Na 2) from 1927 until 1963 where 19 rooms (0.5 million m^3) were created on the 775, 750, and 725 m-levels. About 50 percent of this volume was backfilled.

Besides the main shaft, Asse 2, there are four local access shafts within the mine.

The Asse II mine was acquired by GSF in 1965 for the research and development program for disposal of radioactive waste. A railroad spur was built, surface facilities (see Photo Nos. 8-1, 8-2 and 8-3) as well as the underground portions of the mine significant to the new utilization (see Photo No. 8-4) were reconstructed; the Asse 2 shaft was extended to the 750-meter level, in particular. A new shaft, Asse 4, was sunk reaching a large cavity (10,000 m^3) in a shape of prolate ellipsoid (37 m high, 24 m maximum diameter) with its top situated 185 m below the lowest existing mine workings at the 775-meter level.

8.1.3 Brine Migration Test Site Geology

The area selected as the brine migration test field is located at the 800-meter level southeast of the safety pillars around shaft Nos. 2 and 4.

The geological conditions at the test site, as shown in Figures 8-3 and 8-4, have been interpreted from the existing headings and borings at 800, 775, and 750 m levels. For a more detailed discussion, see Appendix A.

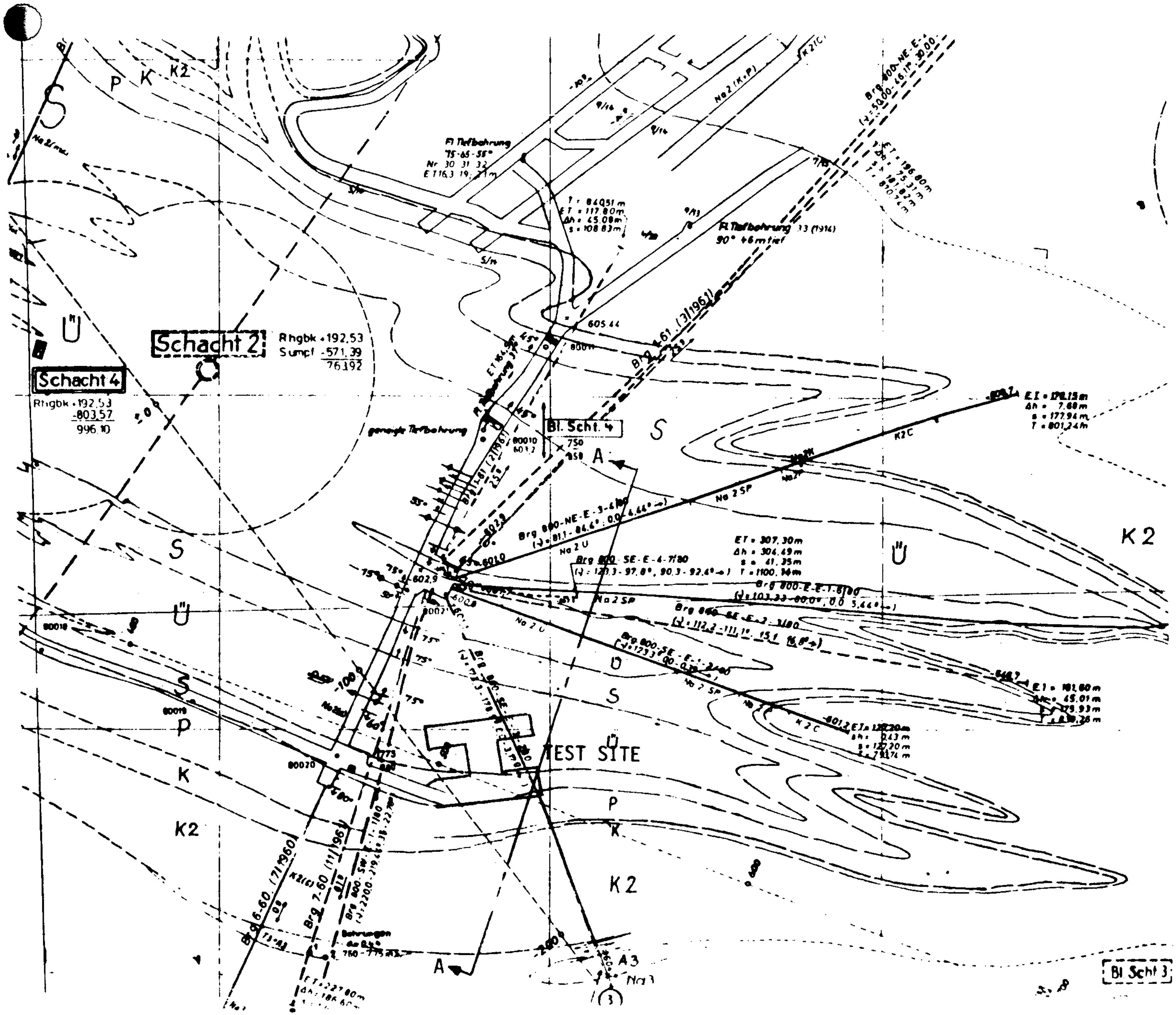

Figure 8-3. Cross Section Mine Geology - 800 Meter Level

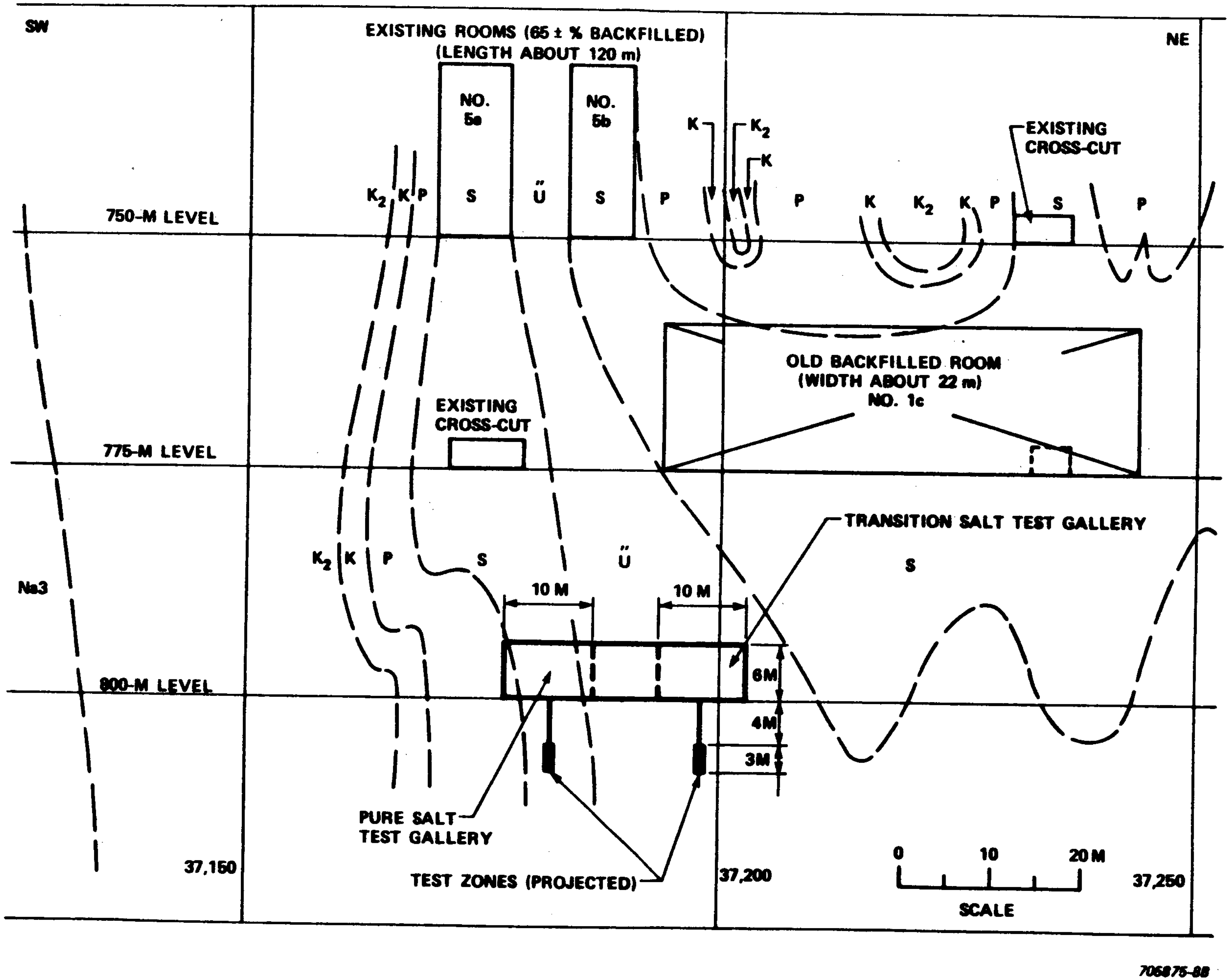

Figure 8-4. Vertical Geologic Section Through Test Site, Section A-A From Figure 8-3

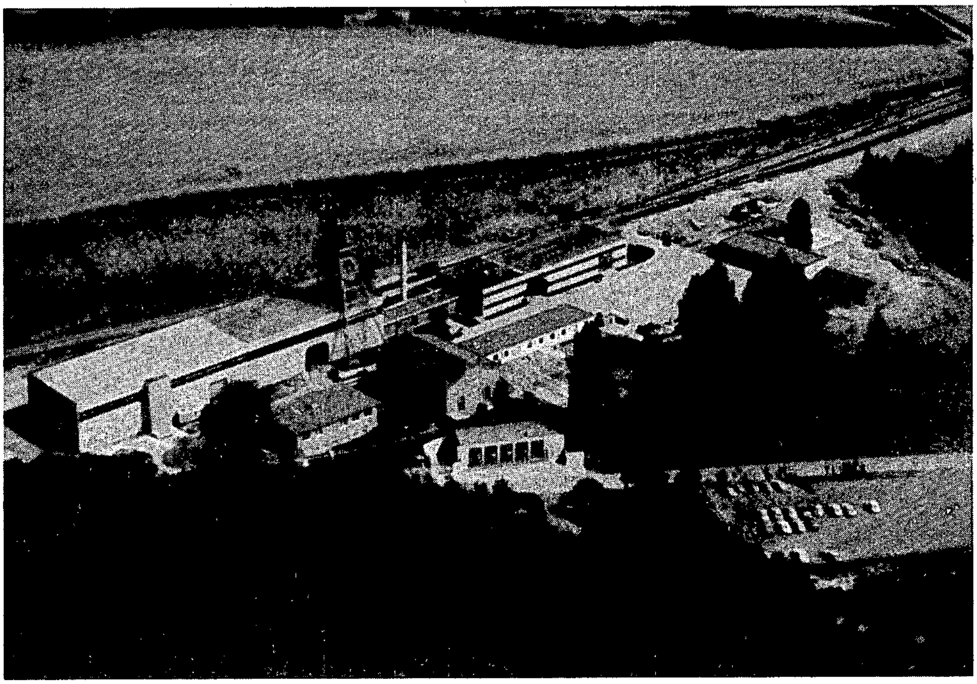

Photo 8-1: Aerial View of the Asse II Mine Facility with a Shaft and Road/Railroad Access

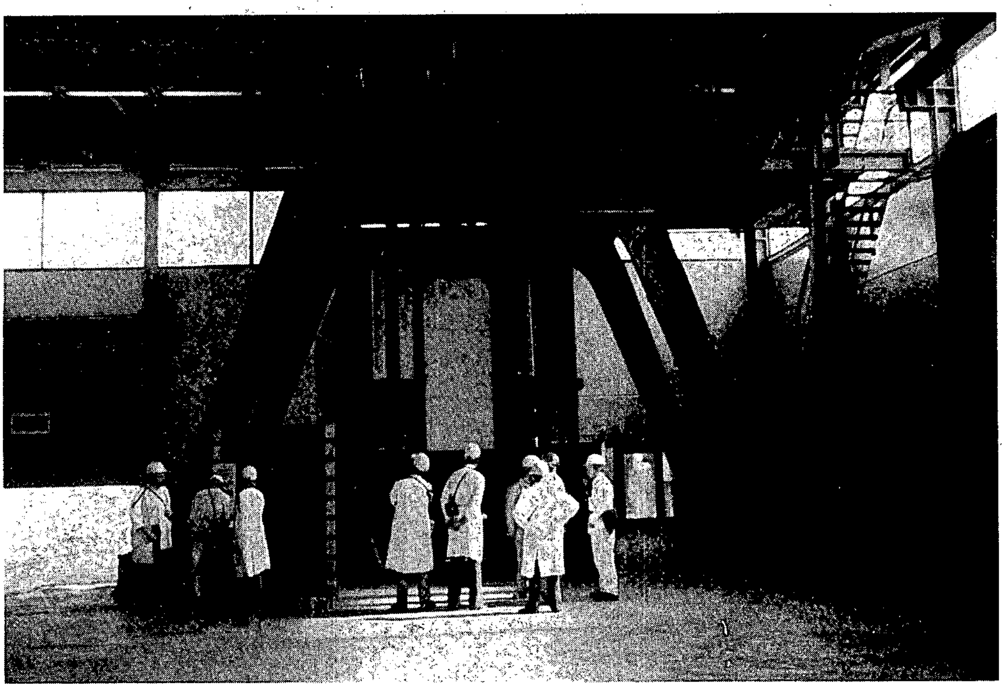

Photo 8-2: Receiving Hall with Shaft No. 2

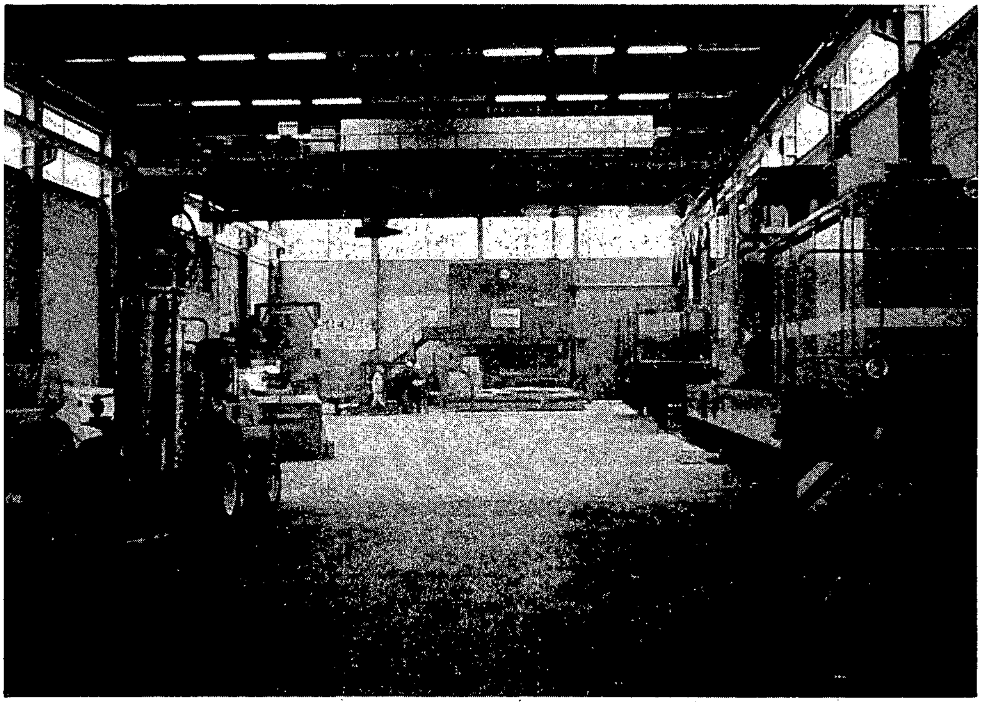

Photo 8-3: Receiving Facility at the Ground Level

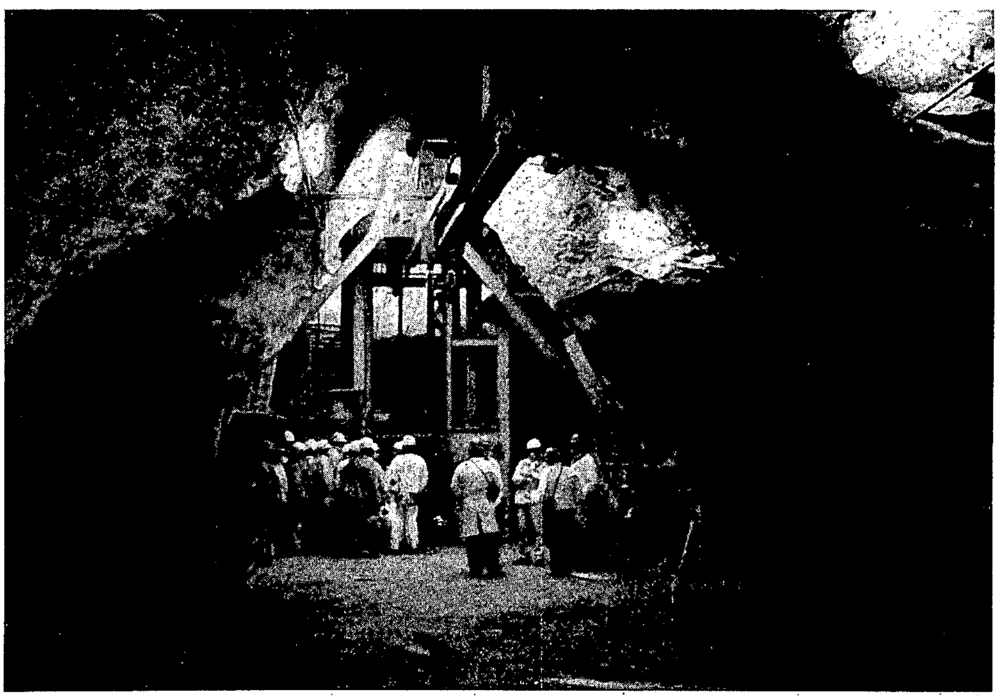

Photo 8-4: Ten-Ton Hoist Next to the Shaft at the 750-Meter Level

8.1.3.1 Lithostratigraphy

The stratigraphic sequence of the encountered strata is presented in Table 8-1.

TABLE 8-1

STRATIGRAPHY OF ASSE MINE

ZONE		SYMBOL	THICKNESS
Hanging Wall:	Layered Halite (Liniensalze)	Na3 (Younger Halite)	Developed only randomly in south
	Potash-Seam Sassfurt/Carnallite (Kaliflöz Stassfurt)	K2	30 ± 20 m
	Kieseritic Transition Salt (Kieseritisches Übergangsalz)	K	Maximum 5 m
	Halite with Clay Layers (Tonliniensalz)	T	In outermost north only
	Halite with Polyhalite Beds (Polyhalitbänkchensalz)	P	Maximum 16 m
	Pure Halite (Speisesalz)	S	About 8 - 10 m
	Transition Salt (Übergangsalz)	Ü	0.5 - 50 m
Foot Wall:	Stassfurt - Main Halite (Stassfurt Hauptsalz)	Na2 beta (Older Halite)	Not identified at the 800 m level (occurs deeper)

Description of the Stratigraphical Sequence

Main Halite (Na2 beta): It does not reach the 800 m level with its characteristic features but rather falls into a special facies described below.

Transition Salt (Ü): Its main component consists of white rock salt, however, it shows strong variation in composition (see Photo Nos. 8-5 and 8-6) and in bed thickness (a few decimeters to 50 meters). It is also affected at variable distances by individual sulfate seams, as well as by polyhalite content. Thin layers of sulfates (polyhalite-anhydrite) in thicknesses between 1 cm (most often) to 5 cm (seldom), which often have gray stripes and are heavily folded, are characteristic for this facie. The sulfate seams are normally composed of

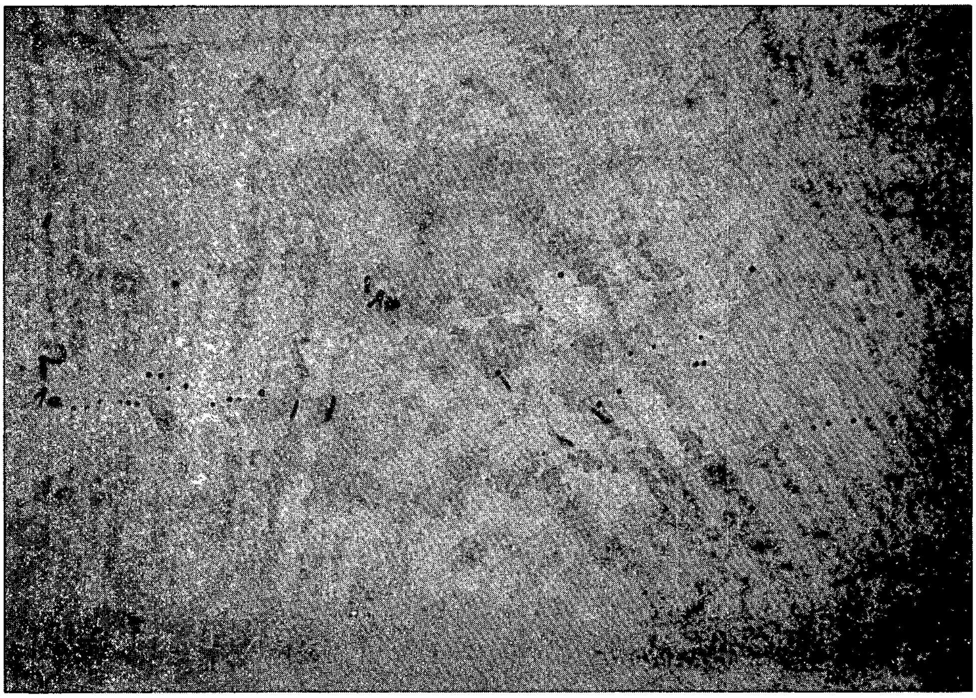

Photo 8-5: Northwest Wall of the Curved Heading at the 800-Meter Level Pure Salt (S) to the Left; Transition Salt (Ü) at the Center and Right

Photo 8-6: Microfolded Anhydrite Seam at the 750-Meter Level

anhydrite, occasionally containing polyhalite. Brine seeps from some anhydrite layers (see Photo Nos. 8-7 and 8-8).

Pure Salt (S): This 8 to 10 m thick layer overlays the Transition Salt. It also exhibits strong variation in form; mostly it is fine to medium crystalline and transparent to white (see Photo No. 8-9). Transparent inclusions (aggregates) of crystal salt are typical. Such zones can extend for several meters and contain an abundance of very small brine inclusions. Occasional 1 to 3 cm seams with slightly yellow-white layers consisting of halite with polyhalite and also anhydritic impurities clearly stand out in this pure salt.

Halite with Polyhalite Beds (P): This strata lies above the Pure Salt. It has a maximum thickness of 16 m and consists of fine to medium size crystalline rock salt with yellowish, reddish and gray polyhalite seams of variable thickness (reaching up to 60 cm) and spacing (see Photo No. 8-10). The seams of polyhalite developed from the primary anhydrite layers during the diapirism.

Clayey Salt (T): Its occurrence at the planned test site is unlikely.

Kieseritic Transition Salt (K): It normally lies above the polyhalitic salt as a 0.5 to 5 m thick transition to the Strassfurt/Carnallite (K2). It consists of mostly light gray, seldom yellowish to reddish, fine crystalline halite with single polyhalite layers and numerous white layers of kieserite. The surface of the hygroscopic kieserite layers turns to a white powdery "blooming" epsomite through increase of the content of the crystalline water by addition of water absorbed from the mine air humidity.

Potash-Seam Strassfurt/Carnallite (K2): It is developed predominantly as "brecciated carnallite" up to 50 m thick. This strongly folded and shattered structure is always recognizable as being the base part of the strata by the presence carnallitic kieseritic halite. At the south flank, below the 725 meter level, in particular, the upper part of the carnallite strata is mostly well stratified and bedded. It consists of intercalated layers of raspberry red carnallite, white kieserite and gray halite which alternate with several

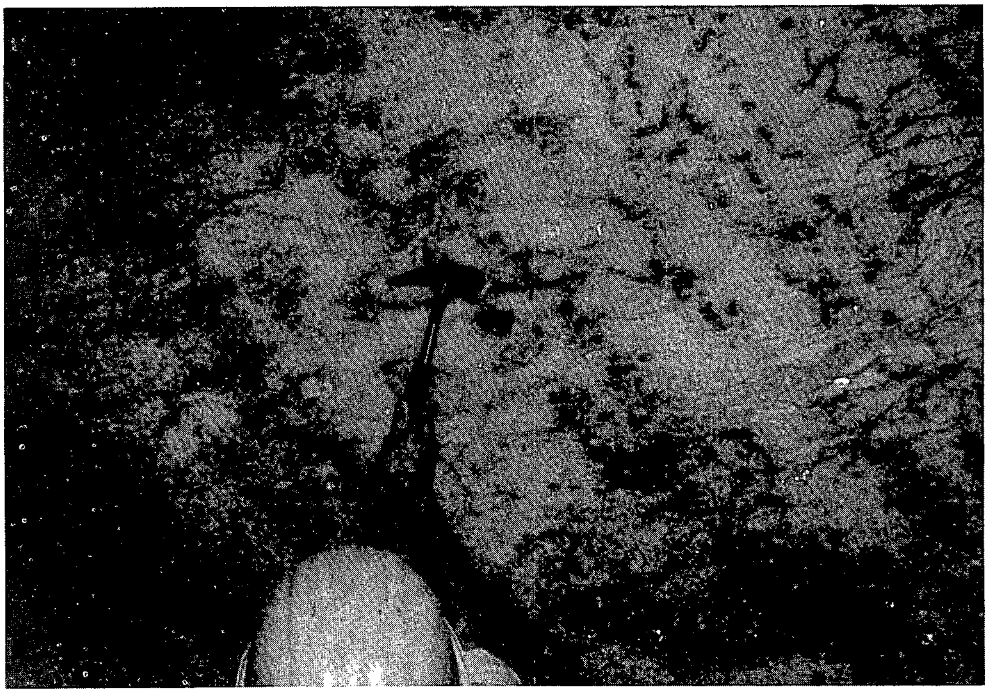

Photo 8-7: Precipitated Brine on the Northwest Wall of the East Heading

Photo 8-8: Precipitate of Brine Overflow from a 30 ± mm Boring Next to an Extensometer in a Wall in Temperature Test Field 4

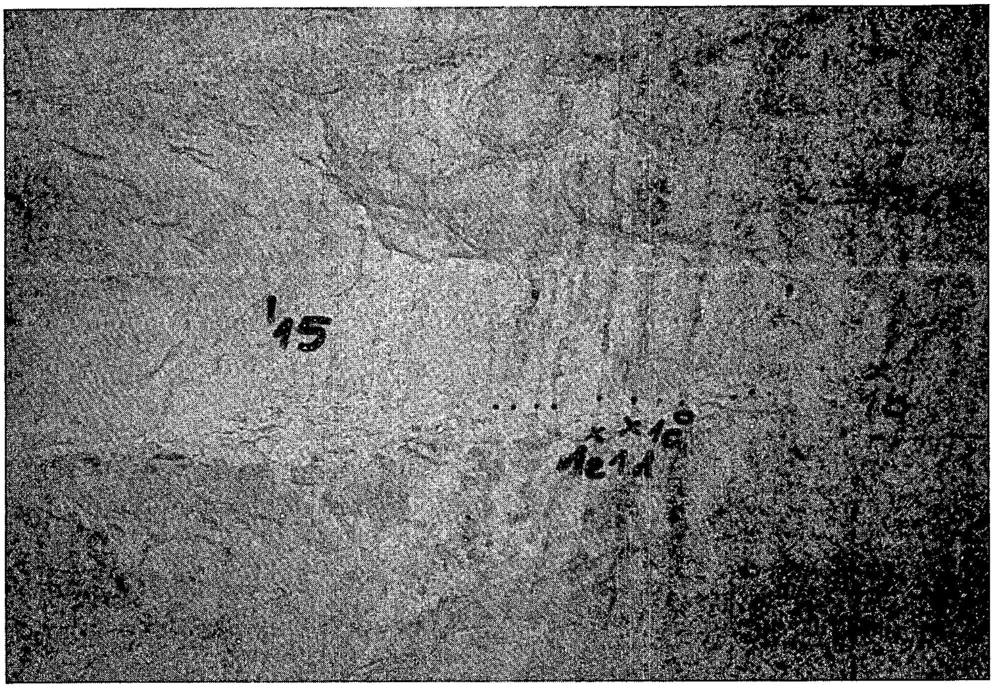

Photo 8-9: Northwest Wall of the Curved Heading at 800 m Level Pure Salt (S) to the Left (Vicinity of Point 15); Transition Salt (Ü) at the Center and Right

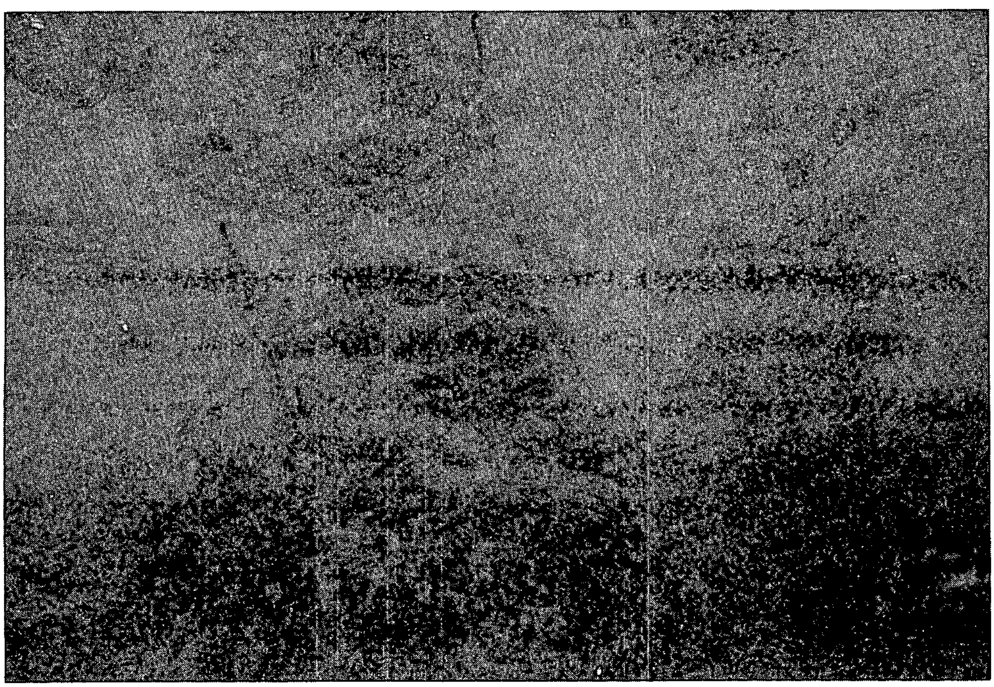

Photo 8-10: Polyhalite Layer in Cross-Cut South of the Potential Test Area

halite beds of thickness greater than 10 cm (see Photo No. 8-11). The layered structure has tectonically shattered zones and indicates transition to brecciated development only locally.

Younger Halite (Na3): Generally, it lies above the carnallite. It consists of halite with anhydrite seams, but it has no effect on the establishment of the planned test field, because this halite is not present in the core of the anticline.

Data on NaCl Content of the Above-Mentioned Strata

STRATA	SYMBOL	PERCENT OF WEIGHT OF NaCl		
		AVERAGE	MAXIMUM	MINIMUM
Transition Salt	(Ü)	89.6	97.8	82.4
Pure Halite	(S)	98.4	99.4	97.7
Halite with Polyhalite Beds	(P)	94.0	97.8	88.6
Kieseritic Transition Salt	(K)	78.3	86.4	68.2

8.1.3.2 Internal Salt Structures and Spatial Distribution

The main Asse anticline is encountered throughout the 800-meter level as shown in Figure 8-2. However, the more detailed Figure 8-3 shows the development of secondary folds in the vicinity of the proposed test area. This is specifically evident in the case where a sharp change in direction of the strike of the potash seam occurs. The individual folds in the area of the east cross heading are predominantly plunging to the east, while those west of the shafts 2 and 4 plunge to the west. In the center of the core of the main anticline, the transition salt forms an upfold (arch), the roof of which is intensively folded by synclines of pure salt.

The area of the brine migration test site is situated at the border of the central part of the Asse main anticline to the east of the gallery to Blind shaft

Photo 8-11: Carnallite in a Cross-Cut South of the Potential Test Area

4. In this region, both Pure Halite (S) and Transition Salt (U) layers are encountered. The southern wall of the test site may lie at the border between Pure Halite (S) and the so-called Halite with Polyhalite Beds (P). The two test locations within the Transition Salt will be situated near the center of a local anticline so that they will stay completely within the Transition Salt. Both test locations within the Pure Halite should be situated near the center of the Pure Halite layer because the dip of this layer is almost vertical. The final information about the true dip will be obtained by the planned core drillings and excavations into the test area.

8.1.3.3 Expected Moisture Conditions

The water content of about 200 samples of Older and Younger Halite with different mineralogical compositions have been determined during the past studies at Asse (Jockwer, 1979). This investigation showed that the water within the rock-salt exists in four different forms:

- Hydration-water of various minerals - Its amount is proportional to the mineral components. The release temperature of this water form depends on the mineral constituents (e.g., polyhalite and kieserite whose release temperatures are between 180 and 240 degrees Centigrade).
- Crystal boundary surface water - This water form is absorbed at the crystal boundary surface, its amount depends in part on the crystal size. The release temperature is less than 200 degrees Centigrade.
- Brine inclusion droplets within negative crystals - These inclusions are between 0.01 to 0.1 mm. Some, up to 5 mm in diameter, exist mainly in formations where solution metamorphism took place (secondary halite). In primary halite, these inclusions are very small and developed along distinguishable planes.
- Water molecules trapped (fixed) within the crystal lattice - The diffusion velocity of this water is very low and the temperature of release is comparatively high; hence, this type of water is beyond consideration.

All these water forms may be liberated and subsequently migrate by temperature, vapor pressure, or concentration gradients to the heat source.

The distribution frequency of the studied samples (not limited to samples from the test area) shows variation of water content from about 0.01 to 0.7 percent by weight, mostly attributed to the differences between various strata (depending on mineral constituents). Fifty-five percent of the tested samples had water content less than 0.1 percent with a maximum at 0.04 percent (peaking between 0.02 and 0.05 percent) which appears to be typical for halite with little impurities such as in Pure Salt (S) and Transition Salt (U). The higher values (about 0.1 percent) have to be attributed to strata containing higher percentage of mineral impurities, such as polyhalite, kieserite, anhydrite, sylvite, or carnallite.

Table 8-2 presents a summary of water content data on 14 samples from the investigative boring into the brine migration test field determined by three independent methods:

- Karl-Fischer Titration
- Du Pont Water Measurement Instrument (Water specific)
- Thermogravimetry

Extreme values for two samples of relatively pure halite in the Transition Salt Strata were not included in the summary. The measurement results indicate very good correlation between the individual methods for particular samples. Differences between samples were considerably greater. Water content of Pure Halite (S) ranges from about 0.01 to 0.06% and of Transition Salt (U) from about 0.14 to 0.60%. These values are respectively less and greater than had been expected. Further samples will provide more data as the test areas are excavated.

8.1.3.4 Other Rock Properties

During the course of research work at Asse, a great volume of rock property data has been gathered. They are contained in many unpublished and published reports and papers. The existing data most pertinent to the brine migration testing in the "S" and "U" layers have been summarized in this section.

TABLE 8-2

WATER CONTENT OF SAMPLES FROM INVESTIGATIVE BORING FOR BRINE MIGRATION TEST FIELD

Test Method		Water Content % (of Weight) In Salt Type	
		Pure Halite Na2S	Transition Salt Na2U
1. Karl-Fischer Titration	Range	0.006-0.063	(0.052)[1] 0.138-0.572
	Average	0.026	0.331
2. DuPont Water Measurement Instrument	Range	0.011-0.064	(0.012) 0.147-0.598
	Average	0.032	0.322
3. Thermogravimetry	Range	0.011-0.054	(0.070) 0.156-0.590
	Average	0.031	0.357

1) Minimum values in ( ) belong to the two samples of relatively pure halite which were eliminated from calculations of the average values.

Table 8-3 presents data on the mineralogical composition of these salts and Table 8-4 on the chemical composition. Both tables also contain values from the investigative boring into the brine migration test field. Tables 8-5 and 8-6 present data on the physical and thermal properties of the salts.

8.2 SITE CHARACTERIZATION STUDIES

The test site characterization studies will be performed during various phases of the test indifferent forms and at different levels of detail, as follows:

- Site Selection Phase:

  - Preliminary site characterization based on available data and limited drilling program

- Preparation Phase:

  Detailed site characterization based on:

  - Testing during the excavation of the access entry and both test galleries.

  - Investigation within the experiment zone using core borings drilled from the test galleries into the experiment zone below the mine floor. These will be drilled away from the individual test sites.

  Pretest characterization based on samples obtained from coring the test holes.

- Operation Phase:

  Characterization during the test consisting mainly of observations and special testing of samples of gases, moisture, etc.

- Post-Test Evaluation Phase:

  Post-test characterization based principally on studies of samples recovered by overcoring.

Individual phases are discussed in the subsequent sections.

TABLE 8-3

MINERALOGICAL COMPOSITION[1]

Mineral	Content in % (of Weight) In Salt Type	
	Na2S[2]	Na2Ü[3]
Halite	98.91-99.87 (99.0-99.9)	81.90-98.75 (85.0-95.7)
Polyhalite	0.17-0.77 (0.5-0.9)	0.06-0.11 (2.4-8.2)
Kieserite	0 (0-0.1)	0 (0.09)
Anhydrite	0-0.30 (0)	1.14-18.00 (0-12.5)
Carnallite	0 (0)	0 (0)
Sylvite	0 (0)	0 (0)

1) Values in ( ) were determined on samples from the investigative core boring into the brine migration test field.

2) Values outside of the indicated range have been detected at one sample containing higher content of impurities (Halite = 96.50%; Polyhalite = 2.93%, Anhydrite = 0.33%).

3) Values for two samples of relatively pure halite were disregarded in indicating the range in ( ).

TABLE 8-4

CHEMICAL COMPOSITION[1]

Chemical Substance:	Content in % (Vol.) (Separately for Cations and Anions) In Salt Type: Na2S[2]	Na2U[3]
Cations:		
Na^+	98.56-99.74 (98.78-99.82)	85.00-97.97 (86.66-96.28)
K^+	0.04-0.16 (0.06-0.19)	0.02-0.10 (0.42-1.62)
CA^{2+}	0.07-0.56 (0-0.28)	1.01-14.93 (1.98-11.90)
Mg^{2+}	0.14-0.73 (0-0.76)	0.06-1.05 (0.98-2.34)
Anions:		
Cl^-	99.14-99.87	84.38-98.99
SO_4^{2-}	0.13-0.86	1.12-15.62

1) Values in ( ) were determined on samples from the investigative core boring into the brine migration test field.

2) Values outside of the indicated range have been detected at one sample containg greater content of impurities (Na = 96.00%; Cl = 97.30%).

3) Values for two samples of relatively pure halite were disregarded in indicating the range in ( ).

TABLE 8-5

PHYSICAL PROPERTIES

Property (Unit)	Older Halite Na2 beta (coarse grained)	Older Halite Na2U (medium grained)
Salt Density ρ (kg/m^3)	2190 ± 14	2204 ± 26
Poisson's Ratio σ (-)	0.26 - 0.28	0.26 - 0.27
Young's Modulus E (N/m^2)	$3.4 - 3.5 \times 10^{10}$	$3.5 - 3.6 \times 10^{10}$
Bulk Modulus K (N/m^2)	$2.3 - 2.6 \times 10^{10}$	$2.5 - 2.7 \times 10^{10}$
Modulus of Rigidity μ (N/m^2)	$1.3 - 1.4 \times 10^{10}$	$1.4 - 1.5 \times 10^{10}$
Lame's Constant λ (N/m^2)	$1.4 - 1.7 \times 10^{10}$	$1.5 - 1.7 \times 10^{10}$
Compressive Strength (MPa) at four different confining pressures (MPa)		
0	24.6 ± 1.5	22.3 ± 1.4
5.0	54.7 ± 1.1	58.4 ± 2.4
10.0	69.1 ± 0.6	71.3 ± 2.1
20.0	82.1 ± 3.1	82.7 ± 1.0
Tensile Strength σ_t (MPa)	1.66 ± 0.15	1.55 ± 0.11

TABLE 8-6

THERMAL PROPERTIES

1. Thermal Conductivity λ [Wm^{-1} x $°C^{-1}$]

$$\lambda(T) = a_0 + a_1T + a_2T^2 + a_3T^3$$

T = Temperature (°C)

a_0 = 5.734 (Wm^{-1} x $°C^{-1}$)

a_1 = -1.838×10^{-2} (Wm^{-1} x $°C^{-2}$)

a_2 = 2.86×10^{-5} (Wm^{-1} x $°C^{-3}$)

a_3 = -1.51×10^{-8} (Wm^{-1} x$°C^{-4}$)

2. Specific Heat Capacity $c\rho$ (Joule x m^{-3} x $°C^{-1}$)

$$c\rho = a_0 + a_1T$$

ρ = density of rock salt (kg/m^3)

c = specific heat (Joule x kg^{-1} x $°C^{-1}$)

a_0 = 1.87049×10^6 (Joule x m^{-3} x $°C^{-1}$)

a_1 = 1.9386×10^2 (Joule x m^{-3} x $°C^{-2}$)

3. Cubic Coefficient of Thermal Expansion

β = 1.2×10^{-4} (1 x $°C^{-1}$)

8.2.1 Preliminary Site Characterization

During the test site selection phase, the locations of all openings, drill holes, drifts, shafts, and other man-made discontinuities relative to the test site have been identified. Also, zones which may affect the stress and moisture distributions around the test site and hence affect experiment results (such as wet zones, faults, shear zones, contact zones) have been mapped.

The characterization of the test site prior to chamber excavation requiring additional coring to determine various specific rock parameters and suitability of the site for the planned test has been essentially completed. Laboratory support required to perform mineralogical and chemical analyses on rocks and fluids encountered in the test site area, as well as to determine or confirm some of the basic rock material properties discussed in Section 8.1 is in its final stage in the FRG and in its initial stages in the U.S.

8.2.1.1 Field Investigation

During the second joint US/FRG meeting in September 1980, it was agreed that subhorizontal core borings will be air drilled into the potential area of the test field.

Subsequently, a subhorizontal core boring has been air drilled from an alcove next to the crosscut leading to Blind Shaft 4. A core diameter of 47 mm (2 in) provided sufficient core, which was environmentally protected immediately after recovery. Because the single boring would not intercept all test zones within the test area, it was targeted for test zone interception within the "S" layer, as being more critical. During a macroscopic core logging, samples for laboratory testing were selected and distributed for testing in FRG and the USA. Due to the small diameter and use of air as a drilling fluid, the core was significantly fractured which may reduce the accuracy of water content determinations by releasing liquids from the specimen.

8.2.1.2 Laboratory Investigation

Laboratory investigation is concentrating on selected core samples from the vicinity of the test zones. The following examinations are being performed:

- Petrographic/mineralogic confirmation of the rock type,
- Identification of impurities and determination of their quantity,
- Determination of quantity and type of moisture and its release characteristics,

Determination of other physical properties, such as density, thermal conductivity, specific heat capacity, coefficient of thermal expansion, Young's modulus, and elastic Poisson's ratio is not necessary, because of confidence that they would fall within a range of previous tests.

8.2.1.3 Work Plan Guidelines

Although the activities associated with the preliminary site characterization are prerequisite to the actual brine migration test, the quality controls to assure that this work results in the quality of information required need only provide for the aspects discussed in the following sections, assuming that the full-scale quality assurance program will be instituted in all subsequent phases. This leniency is justifiable considering that the information and data obtained during this phase will not be used for the test evaluation because new data from the exact test locations will be provided later.

The aspects of the work plan guidelines presented in Appendix B are outlined below:

- Preparation of work schedule
- Identification of activity tasks
- Calibration of equipment
- Qualification of personnel

- Verification of calculations
- Documentation of activities

8.2.2 Detailed Site Characterization

This phase of the site characterization will be performed during and after excavation of the access entry and test galleries. The exact location of these openings will be determined after evaluation of the previous investigative phases considering the strata geometry in order to satisfy the test geologic and spatial requirements discussed in Section 5.

8.2.2.1 Investigation During Excavation

The principal activity in this phase will be logging and mapping of the excavation walls with selective sample removal for confirmative laboratory testing of rock and impurities type and moisture content and type.

The geology of the test area has to be reevaluated after the excavation and logging of the access entry is completed in order to adjust the direction of test gallery excavations to follow the strike of the geologic structure.

8.2.2.2 Investigation of the Test Zone

In this phase, vertical or diagonal core borings will be drilled from the test galleries into the test zone below the mine floor. Location of these holes has to be selected with regard to the geologic structure and away from potential test locations to prevent interference with future test holes.

Again, these borings should be air drilled preferably using 75 mm or larger diameters. Expected maximum depth is about 10 m because they should reach at least 3 meters below the bottom of the test zone. Selected samples will be tested and analyzed in the laboratory to confirm the rock properties.

Permeability testing using packers (preferably pneumatic) and dry nitrogen or an inert liquid may be performed in these borings.

The borings could be used as instrument holes (such as extensometers, borehole closure measurements, etc.) depending on their condition and location. Eventually, these borings could be closed with removable plugs for periodic permeability testing during the course of the experiment.

8.2.3 Pretest Characterization

The pretest characterization will be performed in two periods:

- Confirmatory - consisting of core borings in all four test site locations and related laboratory testing discussed in Section 8.2.3.1
- Pre-installation - during which all borings for equipment and instrument installation will be examined, as discussed in Section 8.2.3.2.

The results of the post-test evaluation program will be directly compared with the pre-test characterization. This influences the needed precision in locating the samples. A recommended procedure is discussed in Section 8.2.3.3. Because this stage will be a direct part of the entire test, all activities have to comply with the quality assurance requirements.

8.2.3.1 Confirmatory Pretest Characterization

In this period, core borings will be drilled at all four test sites, as follows:

- along the axes of the central heater holes for confirmation of the compliance of the site with the geological requirements discussed in Section 4.6.
- at selected auxiliary heater locations to supplement the information obtained from the central heater holes, if deemed necessary.

Field and laboratory investigation procedures are discussed below.

8.2.3.1.1 Field Investigation. The test holes will be cored using air. The minimal required core diameter is about 100 mm (4 inches), allowing completion of the hole by reaming or overcoring to the desired diameter. Coring of the full diameter is preferred in order to obtain exact log of the bore walls. The depth of the test holes is about 6.5 m (21 ft.). A detailed logging of the core and photodocumentation is required. The alignment of the hole must be surveyed.

The test hole may be permeability tested.

In order to facilitate interpretation of test data, measurement of the zone affected by a stress redistribution, floor heave in particular, is desired. Geophysical techniques, such as resistivity or seismic velocity, may be used to evaluate changes in rock properties.

Pre-test measurement of fracture distributions in holes and on cores will be needed to interpret brine migration results. Fractures can be logged from selected cores or may be characterized in situ using geophysical methods or a borehole televiewer-type tool.

8.2.3.1.2 Laboratory Investigation. The rock properties to be determined have been grouped into four major categories:

- Mineralogical and chemical composition
- Physical properties
- Thermal properties
- Time-dependent properties

These property categories are discussed separately in the following sections, realizing that the properties of rock salt are generally highly variable depending on sample purity, mineralogical structure, testing procedure, and numerous other factors.

Obviously, some of the items on the list and the number of individual samples cannot be specified prior to assignment of a specific test area, and others cannot be definitive until work commences on the experiment (e.g., when samples are available). Many of these tests will be repeated in the post-test phase.

Mineralogical and Chemical Analyses

Analysis of salt layers at each test site is important. Such information as types of minerals, chemical composition, degree of hydration, and percentage and type of impurities in both the salt and its inclusions will be used to interpret brine migration results and thermal and radiation effects.

Continuous samples for chemical and water content analysis should be evaluated throughout the heated length at each test site.

Physical Properties

The following properties will be determined:

- Density usually affected by impurities such as anhydrite which may account for the upper bound, while higher porosity samples most likely will result in the lower bound.
- Moisture content and type must be determined at each test site and, if possible, along the heated zone at smaller intervals. High moisture zones should be identified.
- Thermal Conductivity - In spite of the fact that thermal properties have been previously determined, it may be necessary to repeat these measurements with more explicit quality control.

8.2.3.2 Pre-Installation Characterization

After completion of the central heater holes and drilling the remaining guard heater and instrumentation holes, all holes will be subject of additional observation, measurement and examination, including as:

- Bore scope examination of the hole walls to detect any fractures, grooves, seeps or other features which may affect the brine migration test or the equipment installation. This examination should be supplemented by photographing the center hole walls.
- Note conditions at the bottom of each hole

- Obtain wall sample scrapings from observed unusual locations inside the central holes for additional laboratory testing.

- Measurements in both the central and auxiliary heater holes, such as:

  - hole diameter at several levels

  - depth determination

  - Low gas pressure tests in central and guard heater holes to detect gross leakage through the salt

8.2.3.3 Identification and Selection of Core and Test Sample Locations

Core, sample, and other data collection locations must be clearly identified in order to assure data comparability between the pre- and post-test phases of characterization and to assist in selection of sample locations which will produce maximum benefit to the overall test objective with minimum effort and cost. The following section presents an identification system which is able to accomplish the above objectives.

Sample locations will be selected in both the vertical and horizontal planes. The area of primary interest is around the heated length of the central hole. A following vertical zone distribution is recommended:

1. UZ - Upper Zone, about 3.7 m (12 ft) long zone below the mine floor with limited sampling requirements

2. UTZ - Upper Transition Zone, about 1 m (3.1 ft) long around the upper part of the heater assembly, about 0.6 m (2 ft) long zone

3. PZ - Prime Zone, about 0.6 m (2 ft) long zone along the center of heater

4. LTZ - Lower Transition Zone, about 0.6 m (2 ft) long around the bottom part of the heater assembly

5. HBZ - Heater Hole Bottom Zone, about 0.6 m (2 ft) long reaching about 0.3 m (1 ft) below the bottom of the central hole

The depth of individual zones is to be determined according to the final dimensions of the test assembly and results of the pretest characterization. All sample locations will be identified using radial coordinates with the origin at the intersection of the heater hole axis with a reference plane, such as floor valve the top of the (Example: 2.50 m/N45E/15 cm indicating depth/direction from north/distance from the borehole axis).

8.2.4 Characterization During the Test

This phase of characterization will consist mainly of:

- Observations of the test gallery walls, floor, and ceiling behavior
- Monitoring the instrumentation not directly associated with the brine migration tests[(1)] such as extensometers, room convergence gages, strain gages, etc.
- Special testing of samples of gas, moisture, and precipitates. A need for this type of testing will be determined according to the events and progress of the brine migration experiment

8.2.5 Post-Test Characterization

Post-test characterization is one of the essential activities of the brine migration test. The nongeologic characterization is discussed in Section 13. The geology-related characterization will consist of:

- Central heater holes examination, measurements and wall scrapings
- Drilling core holes
- Other field investigations
- Laboratory investigation

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(1) Data collection and monitoring of instruments related to the brine migration tests are discussed in Section 13.

8.2.5.1 Central Heater Hole Examination

After the hardware and backfill removal, a borescope examination and photographing will be made to compare the wall conditions with those prior to installation of the heaters. This examination should look for evidence of cracking, spalling, mineral growth, and any other observable changes to the walls. Care should be exercised to minimize damage to the walls(2) and to minimize access of moisture to the hole. A written log of observations and locations should be kept and photographs of significant features obtained, if possible.

Collected brine in the central or guard heater hole may collect by gravity at the bottom of the hole. An effort should be made to determine the conditions there because it is unknown whether free standing brine, wet salt, or dry salt will exist at the bottom. Later, an intact salt sampling of the bottom of the hole by a core of about 30 cm length is recommended.

Because samples of fluids, salt, and other materials from the walls of the central heater hole could represent delicate details which may not be preserved with exposure and which may be altered by overcoring and subsequent handling, wall sampling is recommended. In particular, evidence of the actual brine migration mechanism could lie in the thin veneer of the hole circumference. Also, the moisture content and concentration of constituents other than NaCl could relate to brine migration.

8.2.5.2 Drilling Core Holes

Two sets of core holes will be drilled:

- Slightly inclined directional drilling into the central heater zone to recover core in which the original heater hole wall will be preserved.
- Vertical coring into the salt around the central heater hole.

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(2) Depends on the success of the backfill removal.

Pending equipment availability, large diameter overcoring could be also used at selected locations.

Coring should be done with air and with a 100 percent core recovery goal. The original holes should be kept plugged (e.g., using plastic caps) before and during the overcoring operations. Handling, labeling, and logging of the core after removal is discussed in Section 8.2.3.3. Its distribution and storage should be planned so that minimum delays between drilling and testing are encountered.

The overcoring specifications (location, depths, sizes, etc.) will be determined according to the availability of the drilling equipment.

8.2.5.3 Other Field Investigations

Other field investigations will consist primarily of examination and possibly permeability testing of other holes, auxiliary heater holes, and investigative holes from the detail site characterization, as discussed in Section 8.2.2.2. Also, the test gallery faces will be observed, during and after the cooldown period.

Monitoring of the auxiliary instrumentation will continue with increasing time intervals between individual measuring periods.

8.2.5.4 Laboratory Investigation

Brine migration mechanisms may lead to changes in the structure, shape, size, or orientation of salt crystals and fluid inclusions. Therefore, comparative evaluation of characteristics of the pre- and post-heated salts may indicate brine migration of brine migration. The pretest examinations are discussed in Section 8.2.3.2.

Comparative petrographic evaluations of pre- and post-heated salts can be used to examine crystal microstructures and fluid inclusions. Fluid inclusions can be studied on polished samples using a microscope focused below the polished surface.

Brine movement by liquid inclusion migration through the salt grains is expected to produce changes in relative concentration and size of brine inclusions. Methods used to indicate brine migration by examination of fluid inclusions should include:

- Determine density of inclusions at varying distances away from the heater wall.
- Determine the distribution of inclusion sizes within crystals at varying distances from the heater wall.
- Determine comparative differences in inclusion orientation with respect to both crystal orientation and thermal gradient in the pre- and postheated salts.
- Determine moisture content of samples to define the radial distribution of brine around the heater hole.
- Note the presence and characteristics (number, size, shape, orientation) of inclusions which contain vapor bubbles.

Salt samples should be sectioned from the cores at varying distances from the heater hole wall. These samples should then be used for the comparative examination of pre- and post-heated salt as discussed above. Differences in the pre- and post-heated salt samples should be photographed and described.

Based upon the results of the petrographic examination, physical characterization on a smaller scale at higher magnification using transmitting electron microscopy (TEM) or scanning electron microscopy (SEM) may also be warranted, especially for scrapings of the heater hole walls. Energy dispersive analysis (EDAX) could be used to map the distribution of certain elements.

9.0 SAFETY EVALUATION

Safety of this test includes protection of workers operating the test against radiation hazards and the usual fire, electrical shock, etc., concerns. Also, when working with radioactive materials, concerns for the general public are significant. This section identifies these concerns and discusses the approaches to be taken to minimize the hazards involved.

9.1 RADIATION HAZARDS

9.1.1 Production and Transportation

The cobalt 60 radiation source will be produced by a commercial firm which produces these sources as standard items. As such, it has established procedures and obtained licenses for source production, handling, and transportation which will be utilized in the production and delivery of the source to Asse and also for return of the source to the manufacturer at the end of the test.

9.1.2 Insertion of the Source into the Test Sites and Removal

Upon receipt of the radioactive source at Asse in the shielded cask, the source will be removed from this cask into the hot cell at Asse. Subsequently, the source will be reinserted into this cask for transport to the test site, where the source will be installed into the test assembly. When both source canisters are inserted into the test assembly, the shield plug will be installed, the sliding shield closed, and the cask removed. Source removal will be the reverse of these activities. During these operations, normal precautions for handling radioactive materials will be taken, such as trial fits and radiation monitoring. The responsibility for describing these procedures, obtaining required licensing approvals, and carrying out the actions rests with GSF-IfT.

9.1.3 Operation

During operation of the test with radioactive sources installed, the activities required will include radiation monitoring, control of personnel access, and observation of test parameters. These procedures will be developed by GSF-IfT.

9.2 SITE PREPARATION

Site preparation includes excavation of the drifts and installation of utilities in the test site. This will be prepared for and conducted by GSF-IfT. They will use standard practice which includes review and approval by the local mining authorities.

9.3 TEST EQUIPMENT INSTALLATION AND REMOVAL

Installation of test equipment will involve manipulating heavy objects. Normal precautions will be taken for these operations, such as confirming lifting equipment adequacy, etc. These operations will be described by detailed procedures prepared by GSF-IfT from more general procedures provided by Westinghouse. The procedures will receive normal safety reviews.

9.4 TEST EQUIPMENT OPERATION

Potential safety hazards during test operation include the following:

- Radiation Exposure

  Radiation shielding will be installed and surveyed to maintain a low level of radiation in the test operation area. Access to the test area will be controlled so that a radiation trained worker is present whenever access to the equipment is allowed. These are normal procedures and will be documented and reviewed prior to testing and compliance will be monitored during operation.

- Fire

  Fire hazards during operation of the test are associated with electrical equipment, the emergency diesel generator and its fuel supply, and transient operations such as welding or cigarette smoking. Fire is a major hazard in any mine due to the restricted access and escape routes and restricted ventilation which can lead to generation of carbon monoxide gas.

The possibility of fire will be minimized by using equipment and materials that minimize the risk of fire, by design of the test area, by the availability of emergency equipment, and by appropriate training of personnel. Electrical equipment and cabling will satisfy national standards (at place of manufacture) for fire safety and will be applied within its design limitations. The emergency diesel generator will be of special design and qualified for operation in a mine environment. Other operations will be controlled by test operators trained in and aware of the importance of fire prevention. Periodic safety audits will be conducted to assure compliance with safe procedures.

- Electrical Shock

  Electrical shock hazards will be minimized by using only qualified equipment within its design limitations, by safe design of terminal areas, by using qualified personnel, and by periodic audits.

- Thermal Burns

  The only objects with a potential for high temperatures are the moisture collection system test assembly gas outlet line, the emergency diesel generator, and perhaps, some electrical components such as the heater power controllers. Hot objects will be clearly labeled and provided with guards against accidental contact, if necessary.

- Pressure Explosions

  Some components of the test may become pressurized, such as the moisture collection system. These components will be designed to appropriate codes and provided with safety relief valves, as appropriate, to prevent overpressurization. Pressurized gas flasks will be provided with appropriate restraints and will be operated only by qualified personnel. A major item of concern is the moisture collection system condenser, separator, and collector which may be made of glass. The apparatus will be tested at higher-than-design pressure prior to operation and will be protected by plastic or metal screening during operation.

- Mechanical Hazards

  Mechanical hazards include such items as cuts on sharp edges, dropped objects, etc. These hazards will be minimized by conducting a safety review of the design and of the constructed equipment. Qualified operations personnel will be reminded and audited for safe operating practices.

10.0 QUALITY ASSURANCE PROVISIONS

The Brine Migration Test Plan addresses one task in the U.S. program to develop the specific and technological bases and to investigate the engineering feasibility of designing and constructing licensed repositories in several geological formations. Associated processes and equipment must be developed and field testing must be conducted to develop the technology bases required to meet the program objectives.

The U.S. Code of Federal Regulations provides the legal requirements which must be complied with to license nuclear facilities, and defines design basis as "that information which identifies the specific functions to be performed by a structure, system or component of a facility, and the specific values or ranges of values chosen for controlling parameters as reference bounds for design. These values may be (1) restraints derived from generally accepted 'state of the art' practices for achieving functional goals; or (2) requirements derived from analysis (based on calculations and/or experiments) of the effects of a postulated accident for which a structure, system or component must meet its functional goals."

Design bases for some licensed high level radioactive waste repositories will be derived in part from analyses of data obtained during the Brine Migration Test.

The Code of Federal Regulations further stipulates that because nuclear facilities include structures, systems and components that prevent or mitigate the consequences of postulated accidents that could cause undue risk to the health and safety of the public, every application for a construction license must include in its preliminary safety analysis report (PSAR) a description of the quality assurance program applied in compliance with the eighteen requirements of 10CFR50-Appendix B.

Therefore, the Brine Migration Test will be conducted in a manner that will provide valid, traceable data which will fully support repository design bases and the licensing laws and regulations, and the validity and traceability of that data will be maintained by the implementation of a documented quality assurance program which judiciously complies with the eighteen requirements of 10CFR50-Appendix B.

The Field Test Program Quality Assurance Plan issued by Westinghouse defines the applicable requirements of 10CFR50 as they apply to the Brine Migration Test. All participant organizations, and their lower tier subcontractors, will comply with the provisions of the total quality assurance program which apply to their respective work scopes for those tasks which directly relate to the collection of data to be used for future repository design.

The Brine Migration Test Quality Assurance Plan requires, as a minimum, the following.

10.1 PROGRAM ORGANIZATION

The qualified individuals responsible for quality assurance planning, inspection, testing, verifying and auditing of the Brine Migration Test planning and implementation shall be designated in writing and shall be sufficiently independent from those who have direct responsibility for performing the technical operations required by this Test Plan.

The documented program shall provide for the planning and accomplishment of activities affecting quality under suitably controlled conditions by qualified personnel. Controlled conditions include the use of appropriate equipment, suitable environmental conditions for accomplishing the activity, and assurance that prerequisites for the given activity have been satisfied. The documented program shall provide for any special controls, processes, test equipment, tools and skills to attain the required quality and for necessary verification of quality.

10.2 DESIGN CONTROLS

The design of safety-related test articles and equipment shall be defined, controlled and verified. Applicable design inputs shall be appropriately specified on a timely basis, and correctly translated into design documents. Design changes, including field changes, shall be governed by control measures commensurate with those applied to the original design.

10.3 INSTRUCTIONS AND PROCEDURES

Work, test and inspection instructions and procedures shall be established and documented.

10.4 DOCUMENT CONTROLS

Measures shall ensure that critical records documents such as test plans, drawings, instructions, procedures, etc., including changes, are reviewed, approved and released for use by authorized personnel and distributed and used at the locations where the prescribed activities are performed.

10.5 PROCUREMENT CONTROL

Applicable design and test bases and other requirements necessary to assure adequate quality shall be included or referenced in documents for procurement of equipment and services. To the extent necessary, procurement documents shall require contractors and their subtiers to have a quality assurance program consistent with the applicable requirements of this Test Plan.

10.6 TEST CONTROLS

Testing shall be performed and comprehensively documented by qualified personnel. Test reports shall identify the activity to which it applies, the procedures or instructions followed in performing tasks, significant dates and times, test results, unusual conditions encountered, signatures of applicable primary and verifying/certifying personnel, and all other pertinent data.

10.7 SAMPLE IDENTIFICATION, HANDLING, STORAGE AND SHIPPING

Controls shall be established and documented in approved procedures for the identification, handling, storage and shipment of test samples. All test samples shall be uniquely and positively identified and marked using approved formats throughout the test program. Packaging shall be based on the protection a sample will require during handling, storage and shipping.

Samples will be packaged for protection against physical damage, gain or loss of moisture, or any effect which would lower the quality or cause a sample to deteriorate. Packaging shall be adequate to preserve in situ characteristics to be determined through subsequent testing.

10.8 EQUIPMENT CALIBRATION

All measuring and test equipment used to obtain quality-related data shall be calibrated with standards traceable to the U. S. National Bureau of Standards (NBS) (or traceable to internationally-recognized standards which are traceable to NBS) by a formal calibration program. This program will assure that equipment is of the proper type, range, precision and accuracy to provide results compatible with the applicable objectives of this Test Plan. Documented procedures shall be based on the type of equipment, the effect of error on the quantities to be measured, stability characteristics, required accuracy, and other conditions affecting measurement control and test data validity.

10.9 VERIFICATION OF DATA PROCESSING

Data processing for testing which affects the results of the Brine Migration Test Program shall be verified by individuals other than those who performed the original processing. Verifications can be performed by independent review of the processing, or the preparation of alternate calculations. An independent review consists of an evaluation of the assumptions made and the processing method, numerical verification of the calculations, formal checking of all computer input, review of results, and the checking of drawings, graphs and tables prepared from the results. For verification of data processing by comparison with alternate methods of calculation, the results of alternate calculations must be consistent with the original data processing for proper verification.

10.10 NONCONFORMANCE AND CORRECTIVE ACTION

Deviations from instructions, drawings and procedures during conduct of tests or test evaluations shall be identified and documented, and dispositions and corrective actions shall be provided by qualified personnel.

10.11 INSPECTION AND AUDIT

To verify that the requirements of the Brine Migration Test Program and approved work instructions are implemented, each participating organization shall develop and document procedures to monitor work performance. The monitoring procedures shall provide for inspections and audits as needed. Both the internal work of an organization and the activities of their contractors shall be considered. Procedures shall indicate the activities to be monitored and the means for reporting the results. The procedures shall be prepared prior to the performance of the monitoring activity and provide adequate detail so that the objectives, the method to be used for monitoring, reporting requirements and personnel qualifications are described. Inspections and audits of the test and test evaluations shall be performed by qualified quality assurance, quality control and/or other technical personnel, as appropriate for the respective organization's scope of work.

10.12 RECORDS CONTROL

Records control procedures will be established to insure the positive traceability and validation of all quality-related test operations and results. The records required to be maintained include the following documents: test plan, test evaluation test plan, quality assurance plan, drawings, project procedures, measuring and test equipment calibration records, work instructions, field and laboratory logs and test data, field changes, deviation or exception records, photographs of samples and sample locations, inspection and audit report records. Record copies shall be legible, reproducible, identifiable and retrievable, and shall be maintained and transmitted to designated authorities.

10.13 IMPLEMENTATION

The preceding sections provided a summary of the quality assurance requirements for the brine migration test program. This section discusses its implementation.

10.13.1 U.S. Quality Assurance Program

The quality assurance program to be followed by Westinghouse and its subcontractors is described in a QA Plan which Westinghouse has issued. This plan basically provides a framework under which standard Westinghouse QA procedures can be implemented. This plan has been approved by ONWI for use on this program, Reference 10-1.

10.13.2 FRG Quality Assurance Program

GSF-IfT does not operate a formal quality assurance program as is done in the U.S., but they do include in their work and applications the various parts of a QA program which result in a quality product. Since utilization of data provided by this test requires full documentation of quality-related procedures, the ONWI resident at GSF-IfT has been assigned to assist in collection of existing procedures for QA-related operations by GSF-IfT to provide the required QA documentation for this program. This documentation will follow the U.S. Nuclear Regulatory Commission Standard Review Plan format.

11.0 U. S. - FRG INTERFACE

This section defines:

- The proposed interface agreement between the involved parties
- The areas in the experiment which require action by one party and approval by the other
- Decision Matrix basis.

These three items are discussed in the following paragraphs in the order mentioned above.

11.1 INTERFACE AGREEMENT

This section provides the preliminary definition of interfaces which exist between the Federal Republic of Germany (FRG) and the United States of America (USA), or their authorized agents, during the brine migration experiment. The list of interfaces is considered complete at this time. However, circumstances or events may occur or be identified by either or both parties during the course of the experiment which will require the list to be increased, decreased, or otherwise modified. Such increase, decrease, or modification shall be by mutual agreement between the involved parties.

The interfaces existing are of a mechanical, electrical, or administrative (installation procedures, operating instructions, etc.) nature. On a gross definition basis, Westinghouse will supply the following:

1. All mechanical equipment which forms a permanent part of the test setup, exclusive of the radioactive sources. This includes but is not limited to, sleeve assembly, canisters, source support tubes, shield plugs, borehole liners for source and guard heater locations, and guard heaters.

2. All components of the Data Acquisition System (DAS) at the mine site on the surface and within the mine except for the data link cable connecting the site modem to the surface modem, and the surface alarm with its wiring to the data logger and the electrical power supply.

3. All components of the Moisture Collection System (MCS), including male and female halves for every coupling interface with the pressure tubing but excluding the pressure tubing.

4. Procedures relating to installation, operation, and maintenance of the above.

On the same gross basis, the FRG shall supply the following:

1. All mechanical equipment relating to and including any transportation casks, installation casks, transfer equipment, hot cell equipment, lifting and handling equipment, receiving, storage, inspection, assembly, checkout, and installation equipment, radioactive sources, and the equipment or system required to maneuver the assembled radiation canister from the surface cask or hot cell to the test area and insert each canister into the test cavity. This equipment will be capable of reversing the procedure upon completion of the experiment or when any intermediate retrieval is required.

2. All components of the normal power and emergency power supply system required to deliver regulated single phase power to the terminals of each heater controller, and isolated and filtered single phase power to connector outlets in the vicinity of the data acquisition system.

3. The data link cable connecting the site modem to the surface modem in the data acquisition system and a surface alarm activated by the data acquisition system.

4. The pressure tubing which interconnects the test sites with the moisture collection system.

5. All operating and maintenance instructions for the hot cell, mine, and FRG procured equipment, and other operations required to handle, transfer and install that equipment.

6. All aspects for any and all licenses required in FRG for storing, transporting, operating, etc., for any equipment (regardless of supplier) or facility relating directly or indirectly to the experiment preparation, operation, or dismantling. (The U.S. will provide information as required to support this activity.)

7. Labor required to excavate and prepare the test site, and to install, operate and dismantle the test equipment.

8. Geological and geochemical services to evaluate and characterize the salt in the proposed test site.

Specific items exist in each of the categories above which must be resolved in accordance with the detailed schedule. These items will be handled individually by separate correspondence, which must be responded to in a timely manner as stated in the interface agreement. A significant number of these items are of the exchange-of-information nature, and the remainder are of the type which directly influences the design of the experiment. Strict adherence to scheduled dates by involved personnel is of paramount importance in providing a totally acceptable experiment.

11.2 ACTIONS REQUIRING APPROVAL

Throughout the conduct of the experiments, there will be documents, drawings, calculations, procedures, etc., developed by one party which will require approval or review by the other party. The degree of importance of the action relative to the other party's interest is the determining factor as to whether the action requires approval or merely review. Regardless of the requirement for approval or review, both parties agree that a response will be generated within two weeks of receipt of any correspondence relating to the above. Adherence to timely responses will ensure that unnecessary delays to the experiment schedule are minimized.

A preliminary listing of these actions is presented below with the understanding that there will be additions, deletions, or modifications as required and agreed to by both parties.

	Prepare	Approve	Review
Site Characteristic Requirements	W		GSF
Selection of Potential Test Sites	GSF		W
Site Selection Work Plan Guidelines	W		GSF
Site Selection Work Plan	GSF		W
Excavation Methods	GSF		W
Experiment Core Characteristic Requirements	W		GSF
Experiment Coring Methods	GSF	W	
Experiment Core Testing and QA Program	GSF	W	
Overall QA Program Requirements	W		GSF
QA Procedures	GSF	W	
Site Selection Test Results	GSF	W	
Site Characterization Test Procedures	GSF	W	
Deviation Notice Disposition	GSF/W	W/GSF	
Overall Experiment Test Plan	W	GSF	
Installation Procedures (U.S. Supplied Equipment)	W	GSF	
Installation of FRG Supplied Equipment	GSF		W
Operating Procedures (Inc. Decision Matrix)	W	GSF	
Emergency Procedures (Inc. Decision Matrix)	GSF	W	
Post-Test Evaluation Plan	W	GSF	
Post-Test Evaluation Procedures	GSF		
Training Procedures	W	GSF	

Records Retention

Pre-Test Geological	GSF	W	
Pre-Test Equipment Assembly & Install.	GSF	W	
Initial Operation	GSF		W
Operation	GSF		W
Post-Test Evaluation	GSF		W
Daily Log of Mine Operations	GSF		W

11.3 DECISION MATRIX

During installation, operation, shutdown, and post-test evaluation, incidents or conditions may occur which require a deviation from prepared procedures. Under these circumstances, it is necessary to know in advance who will make decisions and what corrective actions are to be taken. This has not yet been completed, but several principals are proposed for further discusssion and definition.

The first consideration is given to immediate safety concerns. These are the responsibility of every individual worker to detect, prevent, or rectify as required. Less immediate safety problems should be reported to the shift supervisor or the test engineer for resolution.

The second consideration is the integrity of the test. Test procedures are written to assure that all test operations are preplanned and that the impact of these operations on the outcome of the test is as desired. When deviations from the test procedures are required, whether due to a deficiency of the procedure or other operational problems, it is important that corrective action be carefully considered. In particular, on-the-spot corrections by operating personnel should be minimized because they may not fully understand the basis for the test. Thus, actions which do not involve immediate safety should be referred to the Test Engineer at the site.

The Test Engineer, who is fully aware of the basis for the test, will determine whether or not the discrepancy will affect performance of the test and is major or minor in nature. If the discrepancy will not affect the test and is minor in nature, he will determine the appropriate corrective action and provide explicit revised instructions to the operating personnel. All such revisions should be thoroughly documented and quickly communicated to the ONWI representative at GSF-IfT and, perhaps, the U.S. participants.

Guidelines for making these distinctions will be developed during preparation of installation and operating procedures and will be incorporated into those procedures.

12.0 TEST PROGRAM SCHEDULE

Figure 12-1 provides the baseline schedule for the test program. It gives an outline of the major steps required to have the test in operation by the end of 1982, with the first heater sites becoming operational in November, 1982. Each site should be in operation for approximately two (2) years, but this may vary depending on the data collected.

Equipment retrieval and post-test site characterization will occur when the test is complete--but have not been shown on the schedule. These items will be added as they become better defined.

BRINE MIGRATION TEST SCHEDULE

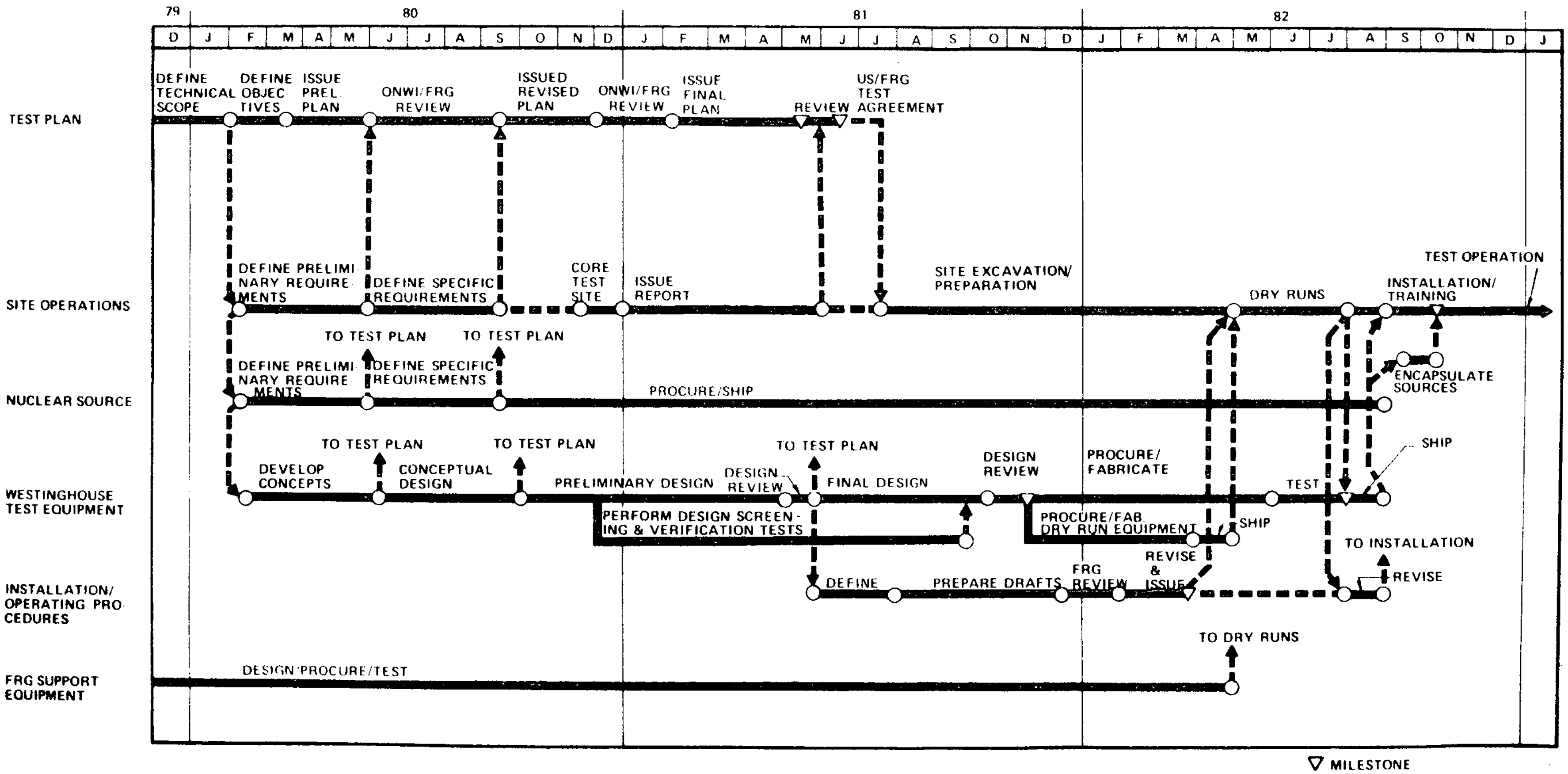

Figure 12-1. Schedule

13.0 INSTALLATION, OPERATION, POST-TEST EVALUATION

The complete performance of the experiment includes operations and the gathering of data during the installation, operation, and post-test evaluation phases. The installation phase is considered to begin with the drilling of the test and heater holes and end at the beginning of the operation phase. The operation phase is considered to begin with the turning on of power to the heaters and conclude with turning off power to the heaters. The post test evaluation phase begins with the end of the operation phase and concludes when the experiment has been completely dismantled and the test sites abandoned.

The intent of this section is to define the actions that need to be accomplished in each phase to permit the maximum benefit from the experiment to be derived. No attempt is made here to develop procedures, however, the following discussion can be used to identify some of the procedures which must be prepared. A test plan must be developed to ensure all of the data is obtained and recorded in a logical and orderly fashion. To a large extent, information developed during the installation and post-test evaluation phases will be of a comparative nature.

The following lists are divided into the three phases of the experiment, with a further breakdown into hardware examination and mine site examination where appropriate.

13.1 SITE SELECTION

This experiment will be conducted in the Asse mine at the 800 meter level. This area of the mine was selected by the FRG because it was the only suitable area in which to conduct the test. Present knowledge about the site indicates that the salt characteristics are acceptable, and the site is sufficiently removed from forbidden areas of the mine to permit conducting the test.

A test core has been air drilled into the area. This core is being evaluated to confirm the validity of the site.

13.2 SITE PREPARATION

Preparation of the site will entail providing entry into the test gallery, excavation of the gallery, coring and drilling of the boreholes for the test sites, guard heaters and instrumentation wells, preparation of the floor and provision of services such as lighting, power and ventilation. Entry and room sizes, methods of excavation, routing of power lines, and ventilation ducts will be determined by FRG designers in accordance with local specifications. Actual operations to accomplish the above will be done by FRG personnel following FRG mining and safety practices.

Access to the proposed test gallery will be done at the discretion of the FRG by either drilling and blasting or by use of a continuous miner. The most likely method for excavation of the test gallery is by a continuous miner. Sizes of the access entry and the test gallery will be determined by the FRG. Limitations on size will be fixed by FRG safety regulations and equipment handling requirements in the gallery with safety requirements having the top priority.

Boreholes in the floor of the gallery will be air drilled for the experiment locations, guard heaters, and instrumentation wells. Cores from these holes, in addition to samples taken during excavation, will be removed and analyzed to generate additional geological data. The tops of holes in the floor will be counterbored so that no experiment hardware will protrude above the floor surface. This will allow for free vehicular passage through the area and minimize the potential for damage to test hardware or injury to personnel.

Services required at the test site gallery include lighting, electric power, ventilation and shop air. These services are probably an extension of existing services from another level or location within the mine. These services will be provided in accordance with existing FRG standards and practices. Equipment supplied by the USA which requires power will be capable of operating on the power supplied. Electrical outlets for the test equipment will be provided by the FRG at locations compatible with the location of the equipment. An emergency power diesel-generator system will be supplied and installed by the FRG.

The routing of power lines and ventilation ducts throughout the mine and their method of support will be governed by FRG specifications covering mine safety and operation. The ventilation requirements, such as air flow and oxygen level, will be to FRG standards.

13.3 INSTALLATION

Installation of the test equipment begins with receipt of the equipment. The equipment must be handled, stored, and inspected for damage. The caisson will then be emplaced in the test boreholes, the seal cast around the caisson, and then the seal must be leak tested. The borehole wall thermocouples will be assembled against the wall. A layer of beads will be laid in place to fill the space below the test assembly. Next, the test assembly will be installed in the borehole. The assembly may be shipped with its internals installed or separately. If shipped separately, the internals would be installed in the sleeve prior to test assembly insertion into the borehole. The completed test assembly will then have its various gas, electrical, and instrumentation connections made and checked out. The guard heaters and instrument probes would be installed as would the mine level wiring, piping, and instrumentation equipment and the sliding shield. Following equipment checkout, trial runs of the radioactive source handling equipment using a dummy source container will be made. The moisture collection system will be operated after test assembly installation to remove any excess moisture from the test hole. Finally, the sources and shields will be installed and the equipment will be ready for startup of the electrical heaters and operation of the test.

13.4 OPERATION

With turn on of the electrical heaters, the test begins the operational phase. No further actions are taken other than to monitor the equipment, collect data, and to react to unusual conditions. The test site will not be normally manned but will be visited on weekdays. The magnetic tape will be changed approximately weekly and periodic maintenance would be performed as required. Some potential unusual occurrences which would require attention will be monitored by the data acquisition equipment which will transmit an alarm to the surface guardhouse. The guard would notify personnel who could react to the situation.

13.5 SHUTDOWN AND DISASSEMBLY

This phase of operation involves heater shutdown, water recovery from the pressurized test sites, radiation source removal and test equipment disassembly. Since it is likely that heater shutdown will cause extensive salt cracking and associated water release, the test sites which have not had continuous water collection will have their water collected before heater shutdown. The central and guard heaters will be shut down completely rather than phased over a period of time, since analysis and experience indicates that the salt will crack in any case. Water collection will continue during cooldown to measure the amount of water released and to prevent water accumulation in the test zone which could alter the borehole conditions.

An unresolved question, as yet, is whether to remove the radioactive sources before or after heater shutdown. There does not appear to be any objection to doing this following shutdown, and doing this before shutdown would require opening the site while hot and retrieving the sources at about 350°C (670°F) which may not be desirable, particularly for the grapple.

The cooldown period required prior to disassembly has not yet been determined, nor has the criterion necessary to determine an acceptable period; however, it is estimated that about one week would be acceptable. Moisture collection will be continued during cooldown. The cooldown is expected to reduce the compressive loads on the test assembly and thus facilitate removal. The test assembly will be removed by installing jacking screws to push down on the salt surrounding the test assembly. After breaking the assembly free, it will be lifted from the salt, either by a hoist installed in the mine ceiling, or by a portable hoist. The caisson will remain installed in the borehole. The assembly should be inspected to determine whether it is encrusted with deposits which may contain significant amounts of moisture. If so, the material should be collected quickly to avoid exchange of water with mine air. Then, the assembly should be protected by sealing the active region in plastic.

The remaining equipment need not be disassembled to satisfy test requirements. It may be abandoned, scrapped, or recovered as decided at a later date. Regarding the electronics, experience indicates that exposure to salt dust will cause the components to become hopelessly corroded upon exposure to surface humidity levels.

13.6 POST-TEST EVALUATIONS

Evaluation of the information generated by the test is started by observing the condition of the contents of the borehole. The borehole should be observed and photographed. If the beads maintain their annular configuration, attempts should be made to collect bead samples from various locations. It is more likely that the beads will slump into a pile in the hole. In that case, the beads should be collected by a method yet to be determined; however, the use of suction is likely. The beads and the hole should be protected against gain or loss of moisture.

The borehole walls should be scraped to remove beads or other deposits. Evidence of salt flowing around the beads, salt cracking, dissolution, or other changes should be noted and photographed. Salt samples should be obtained from the borehole bottom.

With the caisson still installed in the borehole, it would not be easy to overcore the test site. Instead, cores will be taken adjacent to the borehole, possibly at a slight angle to intersect the borehole wall in the test zone. Details on the locations or sizes of cores cannot be completed pending determination of coring capabilities. The objective is to obtain samples of salt from distances up to at least a meter from the test centerline which can be used for petrographic, water content, and mineralogical characterization to compare effects at different distances and axial locations and between test sites. The evaluations to be performed are discussed in the section on geological characterization, Section 8.2.5.

13.7 SITE ABANDONMENT

Following collection of all data and samples from the test site, the site can be abandoned. This activity should follow normal mine procedures, which may include activities such as filling the holes in the floor, salvaging equipment, backfilling the rooms, or barricading the area. These activities should be planned in advance.

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APPENDIX A

GEOLOGICAL DESCRIPTION OF THE 800 m LEVEL AT ASSE FOR THE PLANNING OF THE JOINT US/FRG TEST FIELD FOR BRINE MIGRATION UNDER HEATING

A geological map of the 800 m level in scale 1:1000 (1 cm = 10 m) to serve planning has been prepared (Figure A-1). Exact data are shown on the map only where determined by drifts or borings. The geology in other areas was completed using "constructive" interpretation in order to present the entire picture. The data in these areas are only approximate.

STRATIGRAPHIC SEQUENCE AT THE 800 m LEVEL REGION

ZONE		SYMBOL	THICKNESS
Hanging:	Liniensalze	Na^3 (Younger Halite)	Developed Only Randomly in South
	Kalifloz Sassfurte (Potash-Seam Stassfurt/ Carnallite)	K^2	30 ± 20 m
	Kieseritisches Ubergangssalz (Kieseritic Transition Salt)	K	Maximum 5 m
	Tonliniensalz (Halite with Clay Layers)	T	In Outermost North Only
	Polyhalitbankchensalz (Halite with Polyhalite Beds)	P	Maximum 16 m
	Speisesalz Pure Halite)	S	About 8 - 10 m
	Ubergangssalz Transition Salt	U	0.5 - 50 m
Floor:	Stassfurt Hauptsalz (Stassfurt-Main Halite Na 2 beta)	Na 2 beta (Older Halite)	Not Identified at the 800 m level Occurs Deeper

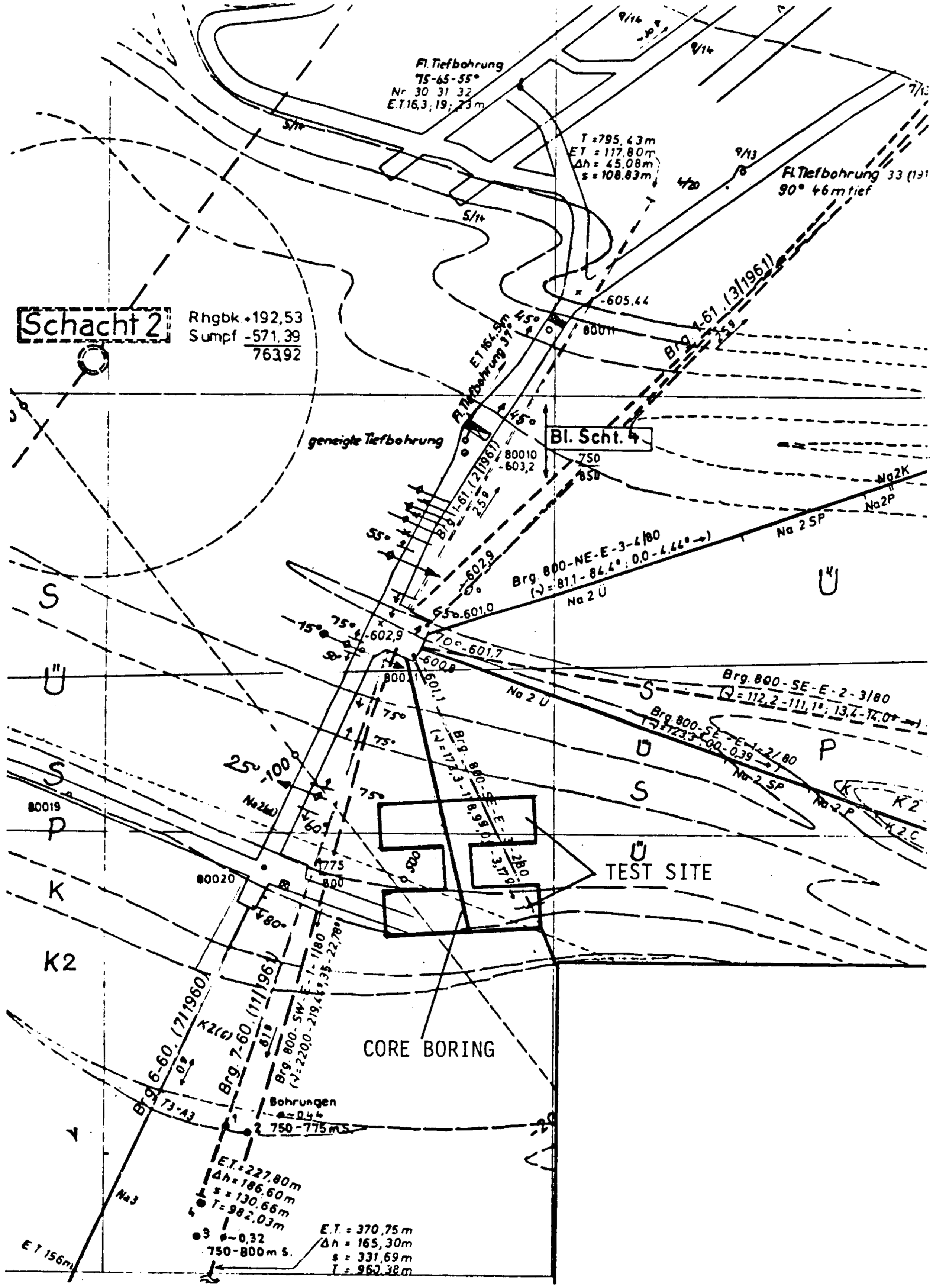

Figure A-1. Proposed Test Site Location and Geology at 800 Meter Level

Description of the Sequence of Strata

The Stassfurt-Main Halite (Na 2 beta) does not reach the 800 m level with its characteristic features (expressions). It was encountered in Shaft No. 4 and in the underlying cavern, as well as in few core borings. The Main Halite consists of colorless transparent to opalescent coarse crystal (grained) rock salt with 1 to 3 mm thick gray anhydrite layers which are repeated over an average distance of 10 cm. The anhydrite is continuously very fine grained. Many anhydrite layers are gently microfolded or undulated and have been; also broken and rewelded during the diapirism (halokinetic uplift of salt). This salt contains many of large crystals up to a length of one decimeter (10 cm) approaching rectangular halite crystals which are oriented with their longer axes in the bedding direction. Sometimes, the edges of the crystals are rounded and broken(chipped).

At the 800 m level, the Main Halite falls into a special facies of Transition Salt (Ü). This salt was encountered in cross-cut and several core borings. The Transition Salt whose main component is white rock salt shows strong variation in composition, in the thickness (between few decimeters to 50 meters), and is also characterized by variable distances between individual sulfate layers, as well as by the polyhalite content. It is characteristic for this facies, besides its stratigraphic position in the uppermost region of the Stassfurt Main Halite, to contain often white to beige, gray striped layers of sulfates (polyhalite-anhydrite) in thickness between 1 cm (most often) to 5 cm (seldom), which are often heavily folded "snakelike" and undulated.

Brine can be seen to drip from individual anhydrite layers, as observed about 30 m south from the Blind Shaft No. 4.

The sulfate seams are normally composed of anhydrite. Only in the south part of the east cross-cut, does the uppermost layer of the Transition Salt consist of polyhalite, as determined by examination of thin sections.

The Transition Salt is overlaid by 8 to 10 m thick Pure Salt (S) which also exhibits strong variation in form. It is mostly fine to medium crystalline and transparent to white. Transparent inclusion of crystal salt are typical. This zone can extensd for several meters and contains an abundance of very small brine inclusions. Bedding can be recognized by slightly yellow-white layers (one to three cm in thickness) consisting of halite with polyhalite and, in a less degree, also anhydritic impurities.

In the hanging wall, the Halite with Polyhalite Beds (P) lies above. It has a maximum thickness of 16 m and consists of fine to medium size crystalline rock salt with yellowish but also reddish and gray polyhalite seams of fluctuating thickness, which can reach up to 60 cm. The seams of polyhalite developed from the primary anhydrite layers due to conversion during the diapirism. They do not continue laterally, but are arranged in groups and pinch out, i.e., the number, thickness, and distance of the polyhalite seams varies very widely.

Above the polyhalitic salt normally lies the Kieseritic Transition Salt (K). Halite with Clay Seams (T) occurs as a facies peculiarity only in the northwest field of the Asse II mine. An occurrence of this halite (T) in the area of the planned brine migration tests does not have to be assumed. That means that an 0.5 to 5 m thick Kieseritic Transition Salt (K) overlies the polyhalitic salt as a transition to the Stassfurt/Carnallite (K 2). It consists of mostly light gray, seldom yellowish to reddish, fine crystalline halite with single polyhalite layers and numerous white layers of kieserite. After a time when the drifts are at standstill, the surface of the hygroscopic kieserite layers turns stepwise to a white powdery "blooming" epsomite through increase of the content of the crystalline water by addition of water absorbed from the mine air humidity.

The Potash-Seam Stassfurt/Carnallite (K 2) above are prevailingly developed as up to 50 m thick "brecciated carnallite." This strongly folded and shattered structure is always recognizable as being the base part of the strata according to the carnallitic kieseritic halite (with the carnallite being mostly light gray). At the north flank of the main anticline at Asse, the upper part of the Stassfurt beds occurs in a brecciated facies as kieseritic-Halitic carnallite with raspberry red carnallite; at the south flank, below the 725 meter level, in particular, the upper part of the carnallite strata (K 2) is mostly well stratified and bedded. It consists of intercalated layers of raspberry red caranallite, white kieserite and gray halite which alternate with several halite beds of thickness greater than 10 cm. The layered structure is only present at tectonically little stressed zones and indicates transition to brecciated development.

Both recessive members of the strata, the Roof Halite (Na 2 r) and Roof Anhydrite (A2r) are normally tectonically absent at Asse, in particular, in the heavily tectonically exposed zone, such; the immediate hanging wall of the mobile carnallite layers. Also, the base members of Zechstein 3 Gray Halitic Clay (T 3) and Main Anhydrite (A 3) are normally missing for the same reason.

Consequently, the Younger Halite (Na 3) of Zechstein 3 generally lies above the Carnallite (K 2). It consists of halite with anhydrite layers, but it has negligible the establishment of the planned test field, because this halite is not present in the core of the anticline.

Data on NaCl content of the above mentioned strata are as follows:

STRATA	SYMBOL	PERCENT OF WEIGHT		
		AVERAGE	MAXIMUM	MINIMUM
Transition Salt	(U)	89.64	97.8	82.4
Pure Salt	(S)	98.38	99.4	97.7
Halite with Polyhalite Beds	(P)	94.02	97.8	88.6
Kieseritic Transition Salt	(K)	78.33	86.4	68.2

Internal Salt Structures

The main Asse anticline was encountered throughout the 800 meter level. However, the main anticline is further divided into several individual folds.

This is specifically evident in the case where a sharp change in direction of the strike of the potash seam occurs. Here, the individual fold axis plunges to the east. The individual folds in the area of the east cross heading are predominantly plunging to the east, while those west of the shafts 2 and 4, in the vicinity of borings 2/61 and 5/1961, plunge to the west.

In the center of the core of the main anticline the transition salt forms an upfold (arch), the roof of which is intensively folded by synclines of pure salt.

The area of the Brine Migration Test Site is situated at the border of the central part of the Asse main anticline to the east of the gallery to Blind Shaft 4 (Figure A-1). In this region, both Pure Halite (s) and Transition Salt (U) layers are encountered. That means one test gallery with two test locations will lie within the so-called Transition Salt, wheras the two other test locations will be within the so-called Pure Halite. The southern wall of the test site may lie at the border between Pure Halite (S) and the so-callled Halite with Polyhalite Beds (P). The two test locations within the Transition Salt will be situated near the center of a special Transition Salt. Both test locations within the Pure Halite should be situated near the center of the Pure Halite layer because the dip of this layer is almost vertical. The final information about the true dip will be obtained by the planned core drillings and excavations into the test area.

APPENDIX B

WORK PLAN GUIDELINE
FOR PRELIMINARY TEST SITE CHARACTERIZATION

As part of the preparation for the brine migration test, a preliminary site characterization will be conducted to determine the suitability of the selected site of the mine to become the experiment zone. Appropriate site characteristics will be determined to substantiate the survey results. Because these activities are prerequisite to the actual brine migration test, the survey controls to assure that this work results in the information required need only provide for the following:

Preparation of Work Schedule

A work schedule defining projected operations to be performed for the preliminary site characterization should be prepared. The schedule can include, as appropriate:

- Review of information previously obtained for the site area
- Planning
- Activity performance (field and laboratory)
- Presentation of results

The work schedule should be compatible with the time frame of the brine migration test.

Identification of Activity Tasks

The individual tasks associated with conducting the preliminary site characterization and defining appropriate site characteristics, along with the approved methods available to perform these tasks, should be identified prior to beginning the work. Methods available to perform the tasks should be nationally or internationally recognized standards whenever possible (e.g., American Society for Testing and Materials, American National Standards Institute, American Petroleum Institute, International Atomic Energy Agency, DIN, etc.) As appropriate, they should contain quantitative (e.g., dimensions, frequencies, and equipment settings) and qualitative (e.g., sample data formats and performance standards) criteria, equipment and material requirements, and documentation and reporting procedures.

Methods should be identified for:

- Drilling and logging of holes.
- Sampling and identification of samples.
- Packaging, handling, storage, and shipping of samples (all samples must retain the in situ characteristics to be determined through testing).
- Field and laboratory testing:
    - Salt type
    - Density
    - Grain size
    - Moisture content, location
    - Young's modulus and Poisson's ratio
    - Thermal conductivity
    - Coefficient of thermal expansion
    - Specific heat capacity
    - Creep
    - Impurity type, content
- Experiment zone excavation.

Methods selected to perform the activity tasks should be made known to all appropriate personnel and be available for reference at the work site.

Calibration of Equipment

All measuring and test equipment used to obtain quality-related data should be controlled by a calibration program. The program should assure that the equipment is:

- Uniquely identified.
- Tagged to indicate the calibration due date.
- Calibrated at prescribed intervals and/or prior to and after testing.
- Isolated and clearly identified as nonconforming should it fail calibration.

Qualification of Personnel

Personnel participating in the preliminary site characterization should be qualified to perform the respective tasks by education, experience, and training.

Verification of Calculations

Calculations performed as part of design analyses or data processing should be reviewed and verified for accuracy by individuals other than those who originated the calculations. Verification, which is the process of formally confirming or substantiating calculations, can be accomplished, as appropriate, by any of the following methods:

- Review of results and spot checking of the calculations.
- Thorough review of assumptions, input parameters and theory, analysis method or model, and results; in addition to complete checking of all calculations and computer input.
- Preparation of alternate calculations using methods of proven validity and comparison with the calculations being verified.

Individuals performing the verification should have technical expertise in the calculation subject equivalent to or greater than the originator.

Documentation of Activities

To provide the necessary evidence of satisfactory work performance and the basis for decisions made, documentation of preliminary site characterization activities should be supplied and retained. Documentation should, as appropriate, include.

- Work schedule.
- Identification of procedures used to conduct the site survey and define site characteristics.
- Equipment calibration records and certificates.
- Personnel qualifications.
- Records of applicable information previously obtained for the site area.
- Field testing and sampling records and drill hole logs.
- Laboratory testing records.
- Design analyses and data processing, along with associated verification.
- Photographs.
- Variances to procedures used.
- Results obtained (e.g., maps, drawings, and data summaries) and decisions made.

The documentation should be controlled and retained by established records administrations systems. Record control should provide for the identification and distribution of records, the removal of obsolete records, and the transfer of records to a storage center. Record retention should provide for receiving records at the storage center, indexing and filing, storage and maintenance, and retrieval for reference or use outside the storage center.

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