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# Interpretation of Hydraulic Tests Conducted in the Waste-Handling Shaft at the Waste Isolation Pilot Plant (WIPP) Site

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# INTERPRETATION OF HYDRAULIC TESTS CONDUCTED IN THE WASTE-HANDLING SHAFT AT THE WASTE ISOLATION PILOT PLANT (WIPP) SITE

Prepared for
Sandia National Laboratories

by

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ABSTRACT

A series of sub-horizontal boreholes from 8- to 41-feet deep were drilled from four depth levels in the waste-handling shaft at the Waste Isolation Pilot Plant (WIPP) site in southeastern New Mexico. The waste-handling shaft is one of three shafts built at the WIPP site to provide surface access to the underground waste repository under construction 2150 feet below the ground surface. The boreholes were drilled at the 782- and 805-foot depth levels in a mudstone and a claystone of the unnamed lower member of the Rustler Formation; at the 850-foot depth level in bedded halite in the upper Salado Formation; and at the 1350-foot depth level in halite, anhydrite, and polyhalite of the Salado Formation. Examination of the cores recovered from one borehole at each level indicated no direct evidence of construction-induced fracturing. Pulse-injection tests were conducted in packer-isolated intervals in six of the boreholes to estimate the formation's hydraulic conductivity and apparent formation pressure, and to determine whether or not there was evidence of construction-enhanced permeability up to one shaft diameter from the shaft wall.

The pulse-injection tests were performed using a multipacker test tool configured to isolate three test zones in each borehole tested. The test tool was equipped with pressure transducers and thermocouples to sense the fluid pressure and temperature in each test zone, and the pressure in the packer-inflation system. Ports in each test interval also allowed fluid injection to impose near-instantaneous pressure pulses on the isolated intervals. During the test sequences, the pulses were shut in and the fluid-pressure responses were monitored with an automated data-acquisition system.

The pulse-injection tests were analyzed using graph-theoretic-field-modeling (GTFM) techniques. The GTFM numerical model can incorporate the

effects of the pretest pressure histories of the test intervals into model simulations of the fluid-pressure response to the pulse injections. The simulations were compared to the observed test data. The analyses were performed in an iterative manner for ranges of hydraulic conductivity and apparent formation pressure to obtain a best-fit match of the model simulations and the observed data. The pulse-injection tests have been affected to an unknown degree by compliance of the multipacker test tool. The compliance effects add a level of uncertainty to the final results.

Acceptable simulations were achieved for most of the tests. The results of the analyses of the tests at the 1350-foot depth level were the most uncertain because equipment limitations and safety considerations prevented the application of pressure pulses significantly greater than the apparent formation pressures. At the 782-foot depth level, apparent pressure communication either through the formation or the test tool or both was observed between the test zones.

Water and gas were produced in boreholes at the 850-foot depth level. In particular, one borehole had an observed inflow, apparently issuing primarily from the shaft liner-to-formation contact. The water inflow filled the boreholes both before and after testing. An attempted pulse-injection test in the test zone closest to the shaft wall at the 850-foot depth level could not be performed because the attempted applied pulse could not be maintained and properly shut in. The test zone included the shaft liner-to-formation contact and the pressure appears to have been dissipated by a discrete fracture in the formation or by the contact itself.

All zones tested except the near-shaft-wall zone at the 850-foot level had low hydraulic conductivities. The analyses indicate a range of hydraulic conductivity between $6.0 \times 10^{-15}$ and $1.0 \times 10^{-13}$ m/s. Considering the limited time available for pretest pressure buildup and for the conduct of the tests, and the uncertainty surrounding the packer-compliance effects of the test tool, the range of about one order of magnitude in interpreted hydraulic conductivity indicates that all zones and geologic units tested have similar and low hydraulic conductivities. The formation pressures determined by the analyses have a moderate degree of uncertainty because they were derived from relatively short-term tests in rocks with low hydraulic conductivity. The time limitations for testing did not allow an adequate pretest period for the buildup of pressure to near ambient conditions before initiating the pulse-injection sequences. The apparent formation pressures nonetheless indicate a pattern in which the tested formations are depressurized within 10 feet of the shaft. The apparent formation pressures at each depth level tested generally increase moving from the shaft into the formations, and increase with depth from land surface. At the 805-foot depth level in the upper Salado Formation near the Rustler-Salado contact, the tested formation has undergone significant depressurization in zones greater than one shaft diameter from the shaft and the formation appears to be depressurized relative to the formations above and below this level.

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## 1.0 INTRODUCTION

The following report describes the objectives, design, equipment, and results of permeability testing in the waste-handling shaft (WHS) at the Waste Isolation Pilot Plant (WIPP) site in southeastern New Mexico (Figure 1.1). The WHS is one of three shafts built at the WIPP site to provide surface access to the underground waste repository under construction at the 2150-foot depth level (Figure 1.2). (A fourth shaft is planned for the WIPP site with construction scheduled to begin in early 1988.) Certain geologic formations intersected by the WHS at four depth levels were tested to determine their hydraulic conductivity. The testing was performed in a series of sub-horizontal boreholes drilled approximately radially outward from the WHS with lengths of 26 to 41 feet. The testing was conducted by INTERA Technologies, Inc. under contract to Sandia National Laboratories (SNL). The testing program was carried out in support of the Plugging and Sealing Program conducted by the Experimental Programs Division of SNL in cooperation with the Earth Sciences Division (Stormont, 1984).

### 1.1 General

The permeability-testing program for the WHS was designed to provide the plugging and sealing program with information on the distribution of permeability, the variation of formation pressure, and, possibly, the distribution of fractures at various radial distances from the wall of the WHS in parts of the lower Rustler and upper Salado Formations. The WHS was excavated using the drill-and-blast technique of shaft construction and the extent to which this technique may have created a "disturbed zone" of enhanced fracturing and/or permeability around the WHS was unknown. The test boreholes allowed the formations in question to be tested at various radial distances from the shaft. The test tool allowed the monitoring of the fluid-pressure responses in the test zone and in adjacent sections of the borehole.

Test boreholes were either drilled or cored at depth levels of 782, 805, 850, and 1320 feet below ground surface. The boreholes were drilled primarily with compressed air as a circulation medium, although some required the use of sodium-chloride-saturated brine as a circulation fluid. The test boreholes were all at least one shaft diameter (approximately 21 feet) long; one test borehole at the 850-foot level was 36 feet long, and the test borehole at the 1320-foot level was 41 feet long. The test boreholes were drilled at a slight downward angle from the horizontal, usually with an inclination of 5 to 10 degrees, allowing the boreholes to be easily filled with fluid during testing. The boreholes at the 850-foot depth level and the southwest borehole at the 805-foot level produced small amounts of water and gas. Production in W850W was apparently from the contact of the shaft liner and the formation. These water-producing boreholes were capped and equipped with pressure gages after testing.

The tests were analyzed with the GTFM numerical model (Pickens and others, 1987) to determine the formations' properties. The model is based on graph-theoretic-field-model techniques. The analyses of the test results were used to determine the magnitude of the formation parameter hydraulic conductivity. The model solution is compared to the measured pressure response and the hydrologic parameters such as hydraulic conductivity and formation pressure are adjusted to achieve a satisfactory match.

## 1.2 Testing Objectives

The objectives of the permeability-testing program in the WHS were as follows:

- Drill and/or core boreholes at least one shaft-diameter in length (approximately 21 feet) at depth levels of 782, 805, 850, and 1320 feet below ground surface.

- Test the boreholes using a multipacker test tool to provide formation-response data in the test zone and zones adjacent to the test zone.

- Interpret the test data and estimate a radial profile of apparent formation pressures and hydraulic conductivities of the formations penetrated by the boreholes.

# 2.0 MULTIPACKER TEST TOOL

## 2.1 Test-Tool Design

The multipacker test tool used for permeability testing in the boreholes in the WHS was designed and built by Baski Water Instruments, Inc. of Denver, Colorado. The tool (Figure 2.1) was designed to allow up to four sections of a borehole, including the bottom-hole section, to be packer-isolated during testing, to allow measurement of temperatures and pressures in the isolated zones, and to allow pressure injection of fluid in up to four test intervals. In addition, the test tool is equipped with a pressure transducer to monitor the inflation pressure of the test tool's packers. To minimize corrosion, the metallic parts of the tool were constructed of stainless steel.

The basic tool configuration used in the WHS boreholes consisted of three packers (Figure 2.1). Using this configuration, the bottom-hole section of the borehole, or zone #1, was tested with one guard zone; the borehole section between packers 1 and 2, or zone #2, was tested with a guard zone on either side; and the borehole segment between packers 2 and 3, or zone #3, was tested with one guard zone. The guard zones were able to detect either pressure communication from the test zones around the packers through the formation, pressure communication due to packer bypass, or pressures induced in zones adjacent to the test zones due to movement of the packers or the test tool during pulse-injection tests. In addition to pressure-induced changes during pulse-injection tests, increases in the packer-inflation pressure could also cause small pressure changes in the test zone due to increases in packer volume, which could cause a pressure increase in a zone as the enlarged packer volume compressed the fluid in an isolated interval. This effect could be partially offset by compensating movements of the sliding end of the packer, which could increase the test zone volume, or by the compressibility and/or hydraulic conductivity of the test-interval formation. Therefore, a waiting time of two hours or more was allowed between packer-inflation-pressure increases and pulse-injection tests to permit any fluid-pressure responses due to the packer-inflation-pressure increases to be distinguished from the fluid-pressure responses induced by testing.

The test tool was instrumented with calibrated strain-gage pressure transducers to measure the test zones' fluid-pressure responses to shut-in and pulse-injection test sequences and to measure the pressure of the packer-inflation system, and with calibrated thermocouples to measure the temperatures of the fluids in all test zones during all test sequences.

Each isolated zone was accessed by stainless-steel tubing which was used to inject fluid into the test zones during pulse-injection testing. All cables for the instruments and tubing for the injection lines were passed through the packer mandrels which were at atmospheric pressure. Between the packers, an o-ring-sealed spacer/shroud was used to carry the cables and tubing and was used to provide test-zone access for the instruments and injection lines (Figure 2.2).

The strain-gage pressure transducers used in the test tool for the WHS testing were 0- to 500-psig gages manufactured by Druck. These instruments record gage pressure and are field calibrated before and after use as described in Stensrud and others (1988). The transducers accessed the test zones by means of feed-through tubes attached to drilled-through Swagelok fittings on the end plugs of the shrouds. The temperatures in the test zones were measured with 4-wire Cromel-Constantan type E laboratory-calibrated thermocouples provided by SNL. The thermocouples were calibrated at SNL's Albuquerque, New Mexico laboratory.

The pressures during testing were visually monitored at the test levels with an instrument panel with pressure gages to monitor the progress of inflation and injection sequences (Figure 2.3). The pressure gages monitor the pressure in each test zone and in the packer-inflation system. The actual monitoring and recording of the fluid-pressure, packer-inflation-pressure, and temperature data were by means of a data-acquisition system (DAS) located at the repository level, 2150 feet deep. The DAS (Figure 2.4) consists of a series of power supplies to access the transducers and thermocouples, a digital voltmeter to read the transducer's and thermocouple's return signals, and a microcomputer to control test-data collection and store and process the data. The DAS was similar to that used in other WIPP-site hydrologic testing activities (see Stensrud and others, 1988). It was housed in a protective container at the repository level.

The pressure for inflation and injection was supplied by two positive-displacement intensifier pumps, each of which was powered by compressed nitrogen. The packers were inflated with fresh water and the pulse injection tests were performed by injecting a 10-pound per gallon (lb/gal), locally supplied sodium-chloride brine into the test zones. The instrument panel was used to monitor the course of the inflation and injection visually and the panel was equipped with a series of valves to allow the packers and test zones to be shut in and disconnected from external pressure sources when the WHS conveyance system needed to be lowered or raised in the shaft.

The drilling and testing in the WHS was performed during the evening and night work shifts. The WHS was available for experimental operations from about 1530 to 0730 hours. The drilling was performed with a compressed-air-operated drill with 5-foot lengths of drilling and/or core barrel. Most of the boreholes were tested about 2 days after drilling. Drilling and testing crews were transported to the test locations on the upper work deck of the WHS conveyance system. Because this system was, at that time, the primary access to the underground workings at the repository level, all drilling and testing equipment had to be removed from the WHS at the end of each work shift to allow day-shift workers underground access. In addition, because of the small amount of clearance between the conveyance system and the shaft wall, no test tools could extend more than 6 inches into the shaft. These restrictions meant that in operating the test tool, the packer-inflation pressure could not be continuously maintained with an external pressure source, but had to be shut in at the end of each inflation episode; the DAS had to be set at the repository level with data-link cables to the test zones; and testing operations such as pulse-injection tests proceeded in approximately 24-hour time steps.

## 2.2 Evaluation of Multipacker Test Tool

To prepare for testing in the WHS, a series of tests were performed on the packers and the test tool to check the integrity of the packers, shroud seals, and fittings. The first test assessed the integrity of the 24- and 36-inch long Baski sliding-end air/water-inflatable packers. Testing consisted of inserting each packer into a 4-inch diameter by 36-inch length of casing, submerging the packer and casing in a tank of water, and inflating the packer with compressed nitrogen to a pressure of 500 to 600 psig. The packers were then inspected for leaks in the elements and fittings. No leaks were observed in the test equipment.

A second test was performed to evaluate the integrity of the shroud seals and fittings using the test-tool configuration that was utilized in the WHS testing program. During the second test, the multipacker test tool was completely assembled with three packers, and the necessary shrouds, thermocouples, transducers, and injection and inflation lines, and installed into a 20-foot, 4-inch diameter length of casing with a sealed end. The packers were then inflated and the mandrel was filled with water. To test for leaks, compressed nitrogen was injected into the test-zone intervals and the pressure was increased to 200 psig. Leakage across the shroud seals or fittings was determined by observing whether or not air was bubbling through the water in the mandrel. No leaks were observed.

Lastly, the control panel was checked by submerging the entire panel with all gages and fittings in a tank of water. The panel was pressured with compressed nitrogen to planned test and inflation pressures and all couplings and fittings were checked for gas leakage and repaired where necessary.

After completing the series of permeability tests in boreholes W782W, W805E, and W850W, the multipacker test tool was removed from the WHS on August 4, 1987 and leak tested to verify the performance and integrity of the test system. The test tool and control panel were subjected to the same tests as described for the pretest evaluation. Each zone was individually tested and the tests were monitored by the DAS to determine if any test interval showed signs of leakage across the packers, shroud seals, and/or fittings. No signs of leakage in the multipacker test tool or control panel were detected.

The testing schedule did not allow time for packer-compliance testing of the multipacker test tool. However, to evaluate the integrity of the assembled test tool, the test configuration of the tools was installed and inflated in a length of 4-inch casing which was sealed at one end. The transducers and thermocouples were connected to the DAS and a pressure pulse was injected into a packer-isolated interval. While observing the test-zone and packer-inflation pressures for 24 hours, the pressures exhibited a diurnal fluctuation of up to 75 psig. The observed variations in pressure correlated with changes in air temperature in the warehouse where the tests were conducted during the observation period. Because of the potential for temperature-induced effects on the isolated-zone pressures during the testing program, the test tool and the fluid used to fill the boreholes were allowed from 4 to 24 hours to equilibrate with borehole conditions before testing. The temperatures recorded by the thermocouples in the test intervals do not show any significant fluctuations after this time. Section 5.7 provides an example of the temperature fluctuations observed during testing.

## 3.0 TEST-INTERPRETATION METHODOLOGY

The tests conducted in the packer-isolated zones in the boreholes drilled in the waste-handling shaft were characterized by significant periods of pretest history during which a pressure skin developed in the formation. The pressure skin consisted of radially varying pressures and resulted in non-ideal conditions for both conducting and interpreting the pulse-injection tests in these boreholes. Testing-program time constraints did not allow pretest shut-in periods of sufficient length to permit the pressure skin to dissipate to predrilling pressures. In low-permeability media, the existence of pressure skins due to borehole pretest history has been shown to have a considerable impact on pulse-test pressure response (Pickens and others, 1987). Therefore, the method of analysis used to interpret the WHS test results needed to be capable of considering the impact of the pretest pressure history. This requirement ruled out the use of standard analytic solutions and type-curve analyses in the test interpretation. The well-test simulator GTFM is a numerical model capable of including the effects of complex borehole pretest history and was therefore selected for use in interpreting the WHS tests.

GTFM was developed using graph-theoretical-field-modeling techniques. These techniques constitute a generalized methodology for modeling the behavior of continuum-type problems based upon linear graph theory, continuum mechanics, and a spatial-discretization procedure. A description of the methodology is presented in Savage and Kesavan (1979). Full details of the theoretical basis and numerical implementation of the graph-theoretical-field-modeling approach for the analysis of borehole-test results are published in Pickens and others (1987).

The idealized physical system modeled by GTFM utilizes the following simplifying assumptions:

1. the part of the formation being modeled is assumed to be homogeneous and confined, with a constant thickness and a finite radius centered on the borehole;

2. all flow is assumed to be radially toward or away from the borehole test interval;

3. the pressure (or head) in the formation adjacent to the test interval is uniform and radially constant at the start of the drilling period; and

4. the borehole and formation fluids are assumed to be homogeneous within the test interval.

Given the above assumptions, a numerical model of the physical system was developed using a generalized graph-theoretical-field-model approach. The GTFM methodology, as applied to the physical system under consideration, results in a set of algebraic equations identical to those derived using finite-element or finite-difference methods.

The modeled system used to simulate the tests has two physical boundaries: the external boundary which defines the radial extent of the formation being simulated; and the internal boundary at the borehole wall. The WHS simulations were all performed using constant-pressure boundary conditions in a formation of 100-meter radial extent to ensure that the prescribed external boundary did not influence the simulated response.

Boundary conditions at the internal boundary are a function of the type of well test(s) being performed and pretest conditions (if any) in the borehole. The pulse-injection tests in the WHS induced a formation response based on an instantaneously applied or withdrawn pressure pulse to an isolated test interval of known volume. Build-up tests which have no apparent initial pressure pulse are special cases of pulse tests. As a matter of terminology, for the remainder of this report all prescribed-pressure tests are referred to as "history" tests rather than the more cumbersome "prescribed pressure".

The pretest period is the period from the time the middle of the test zone is intersected during drilling until the test zone is first shut in during testing. Pretest conditions generally consist of periods during which the borehole remains at a known constant pressure. These periods are referred to as borehole history and are modeled as constant-pressure-history tests.

GTFM differs from analytic well-test simulators in its ability to simulate complex cases where a number of different wellbore boundary conditions are in effect at various times throughout the pretest and testing periods. Figure 3.1 illustrates the elements of a typical test sequence which can be simulated using GTFM. Each period during which the test type remains the same is called a test sequence, thus the example test in Figure 3.1 consists of four test sequences: an initial borehole-history sequence, a slug- or pulse-withdrawal sequence, an intermediate-history sequence, and a final pulse- or slug-injection sequence.

GTFM has been extensively verified through comparisons of test-case simulations to various published analytic solutions. Although no analytic solution exists for tests which encompass the range of boundary conditions present in the WHS tests, the verification results for single-sequence pulse tests with no pretest history are presented in Figure 3.2. The analytic solution developed by Bredehoeft and Papadopulos (1980) was used to generate the test-case data shown on the figure. Additional verification comparisons for GTFM are given in Pickens and others (1987) for other types of hydraulic tests and formation conditions.

In analyzing the WHS tests, two types of test sequences were used: pulse-injection sequences and history sequences, both varying and constant. Pulse sequences were used to model the actual injection test(s) in each zone. During the pretest periods, all the boreholes except W850SE were open to atmospheric pressure. Accordingly, the pretest period for each test was modeled as a constant-pressure history sequence with a specified borehole pressure of 0.0 psig. W850SE produced water and gas immediately after drilling. To avoid excessive inflow into the WHS, the borehole was capped. Pressure built up behind the cap, complicating the pretest history. The pretest period for W850SE is discussed in detail in Section 5.5.

Modeling varying-pressure history sequences involves developing a functional approximation of the actual observed fluid-pressure-response data in the test zones which is then used to define the prescribed wellbore pressure at each time step during simulation of the sequence. Varying-pressure history sequences were used to simulate the initial build-up periods from the time the test-zones were shut in until the first injection tests because the non-ideal pretest pressure responses observed in the test zones precluded accurate simulation of these periods as pulse sequences. The cause of these non-ideal responses was probably due to equipment compliance and/or inter-zone pressure communication either through the formation or packer bypass. The use of varying-pressure history sequences during these periods enabled more accurate simulation of the subsequent pulse-injection test(s).

GTFM simulations assume that flow to and from the test intervals is radial and that the formation is isotropic. These assumptions were developed for testing in vertical boreholes. The WHS tests were performed in slightly-inclined subhorizontal boreholes, making the physical conditions of the test not entirely ideal. The low permeability of the tested formations probably means that only a small part of the rock was affected by the tests and that the radial-flow assumption is probably valid. Of the formations tested, core samples from the boreholes in the evaporite minerals and the halite in the Salado Formation do not display any apparent horizontal or vertical anisotrophy within the actual sections tested. The cores of the claystone and mudstone of the unnamed lower member do not display well-developed laminations, but these rocks are usually characterized by a horizontal anisotropy because of the prefered orientation of clay particles common in these rock types. This horizontal anisotropy can sometimes result in a lowered vertical permeability relative to the horizontal permeability. If the vertical permeability in the formations tested in the WHS were significantly lower than the horizontal permeability, the assumption of radial flow from the test intervals would not be entirely valid. The horizontal anisotropy would result in predominantly horizontal flow from the test interval and the interpreted hydraulic conductivity would be slightly lower than the dominant horizontal hydraulic conductivity in the formation.

Test data from one of the WHS tests were analyzed as if the test had been conducted in a vertical borehole. The test interval for the simulation was developed using a hypothetical borehole with a depth equal to the vertical distance covered by the inclined borehole and a test-interval volume equal to that of the actual test interval. The simulations using this hypothetical borehole indicated a hydraulic conductivity one-half to one order of magnitude higher than the hydraulic conductivity derived using the actual test-interval dimensions and assuming radial flow from the test interval.

In the WHS testing program, the observed formation responses to the pulse tests of the claystone and mudstone beds in the unnamed lower member probably included some combination of radial and horizontal flow. Each test simulation presented in Section 5 shows best-fit simulations and simulations illustrating calculated formation responses for a one-order-of magnitude range of hydraulic-conductivity values. These simulations thus include the range of uncertainty due to the possible nonideal flow conditions which would result if significant permeability anisotropy were present. The uncertainty due to the flow conceptualization applies only to the absolute magnitude of the hydraulic-conductivity values, not to the interpretation of whether or not a disturbed rock zone is present around the WHS.

## 4.0 TEST BOREHOLES

The test boreholes drilled at the four depth levels of interest were completed under the direction of Re/Spec, Inc., under contract to SNL. The boreholes were drilled with standard drag bits or cored with standard diamond-tipped core bits. One borehole was cored at each test level. The nomenclature used by the drillers to identify each borehole was used to catalogue the cores and is contained in the driller's logs presented in Appendix A. The driller's logs were recorded during daily operations on forms provided by SNL. In addition, the chief driller and the driller's assistant provided a separate written account of the operations. Both sets of documentation are provided in Appendix B. For records purposes, the test boreholes were designated by shaft, W for the waste-handling shaft, the depth level, and the sector of the shaft wall where the borehole was drilled. For example, the borehole at the 805 depth level in the southwest sector of the waste-handling shaft was designated as W805SW.

The boreholes in the WHS were drilled and cored primarily using compressed air as a circulation medium, except during the continuation of W805SE, the final 3 feet cored in W805SW, and the coring of W850SE, when sodium-chloride brine was used. Each borehole except W1320E was begun by setting an approximately 18-inch long, 6-inch outside diameter (O.D.) steel collar in the WHS concrete liner.

### 4.1 Depth Level 782 - Unnamed Lower Member of the Rustler Formation

Boreholes W782E, W782W, and W782SE were drilled at the 782 depth level between July 7 and August 1, 1987 (Figure 4.1). The concrete liner at the 782-foot level was approximately 2.08-feet thick at W782E, 2.75-feet thick at W782W, and 2.0 feet thick at W782SE. The core revealed that the unnamed lower member of the Rustler at this depth was a silty mudstone. The physical dimensions of the boreholes at the 782-foot level are as follows:

| Boreholes | Total Depth from Shaft Wall (feet) | Diameter (inches) | Liner Thickness (inches) | Downward Angle from the Horizontal (degrees) |
|---|---|---|---|---|
| W782E | 25.08 | 4 | 25 | 6 |
| W782W | 26.00 | 4 | 33 | 7 |
| W782SE | 8.00* | 4* | 24 | NA |

* Borehole W782SE was started with a 1-7/8-inch pilot bit to a depth of 26 feet from the shaft wall. The subsequent 4-inch reamed borehole deviated strongly from the pilot hole and was abandoned.

### 4.2 Depth Level 805 - Unnamed Lower Member of the Rustler Formation

Boreholes W805E, W805W, W805SE, and W805SW were drilled at the 805-foot level between June 23 and August 22, 1987 (Figure 4.2). The concrete liner at the 805-foot level was approximately 2.08-feet thick at W805E and W805SE, 2.25-feet thick at W805W, and 2.33-feet thick at W805SW. The core revealed that the unnamed lower member of the Rustler at this depth was a silty claystone. The physical dimensions of the boreholes at the 805-foot level are as follows:

| Boreholes | Total Depth from Shaft Wall (feet) | Diameter (inches) | Liner Thickness (inches) | Downward Angle from the Horizontal (degrees) |
|---|---|---|---|---|
| W805E | 26.00 | 4 | 25 | 6 |
| W805W* | 20.50 | 4 | 27 | 6 |
| W805SE | 14.25** | ~4.25** | 25 | NA |
| W805SW | 26.50 | 4 | 28 | 6 |

* Borehole W805W was too severely deviated to install the test tool for testing.

** Borehole W805SE was abandoned after the drilling rods separated and the borehole became enlarged during the extraction process.

### 4.3 Depth Level 850 - Upper Salado Formation

Boreholes W850W and W850SE were drilled at the 850 depth level between July 22 and August 4, 1987 (Figure 4.3). The concrete liner at the 850-foot level was approximately 4.00 feet thick at W850W, and approximately 5.33-feet thick at W850SE. The core revealed that the lithology of the Salado at this depth was bedded halite. The physical dimensions of the boreholes at the 850-foot level are as follows:

| Boreholes | Total Depth from Shaft Wall (feet) | Diameter (inches) | Liner Thickness (inches) | Downward Angle from the Horizontal (degrees) |
|---|---|---|---|---|
| W850W* | 26.00 | 4 | 65 | 6 |
| W850SE | 36.00 | 4 | 64 | 7 |

* Borehole W850W produced water from the area of the cement-formation contact.

### 4.4 Depth Level 1320 - Salado Formation

One borehole was cored at the 1320-foot level, W1320E. The borehole was cored on August 7 and 8, 1987, using compressed air as a circulation medium. No concrete liner is present at this depth level and no collar was set for this borehole. The core recovered from the 1320-foot borehole shows that the downward-angled borehole was cored through approximately horizontal layers of halite, anhydrite, and polyhalite

($K_2Ca_2Mg(SO_4)_4 \cdot 2H_2O$). The borehole began in bedded halite. An anhydrite bed was encountered at 9.3 feet and the core contained an increasing percentage of anhydrite to a depth of 13.0 feet. From 13.0 to 14.8 feet, the core was primarily anhydrite. At 14.8 feet, the borehole intersected a polyhalite layer, and from 14.8 to 17.4 feet the core contained an increasing amount of polyhalite. From 17.4 feet to the bottom of the 41.83-foot borehole the core was primarily polyhalite, with some gypsum nodules. The physical dimensions of the 1320-foot-level borehole are as follows:

| Boreholes | Total Depth from Shaft Wall (feet) | Diameter (inches) | Liner Thickness (inches) | Downward Angle from the Horizontal (degrees) |
|---|---|---|---|---|
| W1320E | 41.83 | 4 | NA | 6 |

## 5.0 BOREHOLE TESTING AND ANALYSIS

Pulse-injection tests were performed in six of the boreholes drilled in the WHS. For testing, the multipacker test tool was configured with three packers. Three tests were attempted in each of the six boreholes except W805SW, where, because of time and access limitations, only two tests were performed. In borehole W850W, test-zone #3 included the interface between the WHS concrete liner and the formation. As noted in Section 4.3 above, this contact produced water and gas. The attempted pulse-injection test of zone #3 could not be completed because a pressure pulse could not be sustained. The pressure pulse imposed on the zone escaped to either an open fracture or to the shaft liner-formation contact too quickly for a proper shut-in pulse to be accomplished.

The successful tests were analyzed using the GTFM well-test analysis model described in Section 3. To simulate each test, the time periods from the midpoint of the drilling of each test zone to the times the zones were shut in were treated as fixed-pressure history sequences with a borehole pressure of 0.0 psig. However, the analysis of borehole W850SE, which became pressurized before testing as described in Section 5.5, used a 30.0-psig fixed-pressure history sequence. For each pulse-injection test, all other preceding time periods, including the test zones reactions to other tests or packer-inflation-pressure increases, are described with varying-pressure history sequences with the prescribed pressure derived from the observed pressure data. A comparison of the differences in results using the varying-pressure history sequences and pulse sequences for pretest borehole history is presented in Section 5.7.

After setting the parameters for the sequences for each test, the pulse-injection tests were simulated and compared to the observed data. The simulations were performed in an iterative manner by choosing discrete values of hydraulic conductivity and formation pressure over relevant ranges, and simulating the tests using each possible pair of those values.

The plots of the best-fit simulations for each test show the best hydraulic-conductivity and formation-pressure matches with additional simulations showing the effect of varying the hydraulic-conductivity and formation-pressure values. A discussion of the sensitivity of the GTFM simulations to variations in the hydrologic parameters hydraulic conductivity and formation pressure follows the description of the results.

All the boreholes tested, except W850SE which was cored with brine, were drilled and cored using approximately 100 psig of intermittently supplied compressed air at the drill and core bits to remove cuttings. All test zones were then left open to atmospheric pressure, except those at W850SE which was capped, until they were filled with brine for testing. A detailed chronology of all drilling and testing activities is presented in Appendix C.

The drillers logs were reviewed to develop pretest history sequences for the test zones. The times when the drilling in each borehole intersected the center of each test zone were used in establishing the pretest constant-pressure-history sequences. The estimated center-of-test-zone drilling times are summarized in Table 5.1. The time periods from the drilling of the midpoint of the test zones to the times when the test zones were shut in, were treated as fixed-pressure history sequences using a constant borehole pressure of 0.0 psig except for the test zones in borehole W850SE which was capped and became pressurized as described in Section 5.5.

All the boreholes except those at the 850-foot depth level were filled with a commercially-supplied, 10-lb/gal sodium-chloride brine before testing. The boreholes at the 850-foot depth level produced water and gas and filled with an apparent brine soon after drilling. These boreholes were not refilled with the commercially-supplied brine before testing.

The multipacker test tool was installed in each borehole and each packer-isolated zone was monitored with a separate pressure transducer and thermocouple throughout the testing periods. The packers were inflated to approximately 500 psig after allowing about two hours for temperature equilibration. The test zones were shut in from 30 minutes to 2 hours after the packers were inflated, except in borehole W805SW where borehole conditions were allowed to stabilize for about 18 hours between packer inflation and test-zone shut in. In each borehole, the packer-inflation pressure, which was monitored with a separate pressure transducer that measured the total inflation-system pressure, declined during a one-day compliance period following packer inflation and shut in. The compliance period refers to the early-test time period when most of the packer adjustment or compliance in response to inflation occurs. After the compliance period, the packer-inflation pressures were increased to approximately 500 psig before the beginning of the first pulse-injection test, except in borehole W805SW.

Each pulse-injection test analyzed is discussed separately in Sections 5.1 to 5.6. The simulations of the tests in each of the packer-isolated intervals were compared to the test data, and these data are plotted with each set of simulations discussed. Each pulse-injection test was analyzed individually although the monitoring periods for the first zones tested extended into the testing periods of later tests and may have included fluid-pressure responses to these later tests and to packer-inflation-pressure increases. The formation and fluid properties used in the analyses are summarized in Table 5.2. Tables A3.1 to A3.6 in part A, Appendix A of Stensrud and others (1988) contain a complete tabulation of the fluid-pressure responses in all zones of each borehole tested and in the packer-inflation system.

The following sections describe the testing periods in each borehole and the results of the GTFM analyses. Table 5.3 summarizes the tests and analyses. The results of the analyses are presented in order of increasing depth in the WHS. At the 805 and 850 depth levels, two boreholes were tested and the testing results are presented in the chronological order of testing. Within each borehole, the tests are also discussed in chronological order of occurrence. The boreholes that were tested and the dates of testing are summarized as follows:

| BOREHOLE | TESTING PERIOD |
|---|---|
| W782W | July 17 to 22 |
| W805E | July 10 to 15 |
| W805SW | August 26 to 31 |
| W850W | July 27 to August 03 |
| W850SE | August 18 to 24 |
| W1320E | August 08 to 17 |

## 5.1 Borehole W782W

W782W was drilled in a silty mudstone bed of the lower unnamed member of the Rustler Formation (Section 4.1). Pulse-injection tests were p0erformed in three packer-isolated intervals in borehole W782W from July 17 to July 22, 1987. Figure 5.1 shows the configuration of the multipacker test tool in W782W during these tests. Borehole W782W was left open after drilling and was exposed to atmospheric pressure for approximately 63 hours after drilling.

The packers were inflated to approximately 500 psig on July 18, and the test zones were shut in 30 minutes after packer inflation. For unexplained reasons, zone #3 was the only test zone that showed a significant pressure buildup during the pretest shut-in period (Figure 5.2). The pressure responses of zones #1 and #2 exhibited only minor pressure increases during the shut-in period before the start of the first pulse-injection test in zone #1. Figure 5.2 is a linear-linear sequence plot of the entire W782W testing period showing each pulse-injection test and the variations in packer-inflation pressure throughout the testing period.

The packer-inflation pressure was increased to approximately 517 psig after a one-day compliance period. During the compliance period, the packer-inflation pressure declined approximately 178 psi. After the compliance period, the following pulse-injection tests were performed: a 113.3-psi pressure pulse was applied to zone #1 on July 18; 108.3-psi pressure pulse was applied to zone #2 on July 20; and a 99.4-psi pressure pulse was applied to zone #3 on July 21.

The pulse-injection test of zone #1 began at 1900 on July 18. The pressure in zone #1 was increased by 113.3 psi during the injection (Figure 5.2). In addition to the fluid-pressure response in test zone #1, zones #2 and #3 and the packer-inflation system responded to the pulse injection within 30 seconds, but the magnitude of the initial responses was less than 7 psi. The fluid pressure in zone #2 continued to rise during the zone #1 pulse-injection test. Similarly, the fluid-pressure response in zone #1 was strongly affected by the zone #2 pulse-injection test. The zone #1 pressure rose 27.7 psi during the zone #2 pulse injection, and rose an additional 5.5 psi during the first 2 hours after the zone #2 test and stabilized at that level. The zone #1 pressure rose an additional 2 psi during the zone #3 pulse injection. The zone #1 pressure stabilized during half of the zone #3 pulse-injection period and then exhibited a gentle rise for the remainder of the testing period. These sympathetic pressure responses clearly indicate pressure communication between zones #1 and #2 in borehole W782W. The exact mechanism of the pressure communication is not known, although the pressure was probably communicated either through the test tool, through the formation, or by packer bypass, or through a combination of all these mechanisms. However, the pretesting evaluation of the multipacker test tool revealed no leaks (see Section 2.2).

The zone #1 pulse-injection test was simulated with a pulse sequence. Attempted simulations of the zone #1 fluid-pressure response after the second packer-pressure increase, and after the zone #2 pulse-injection test, were performed using pulse sequences in which the applied pulse was equal to the zone #1 fluid-pressure increase in response to these events. The same simulation parameters as were applied to the zone #1 pulse-injection-test response were used for additional pulse-sequences.

Simulations were developed for the analysis of the zone #1 pulse-injection test using a range of hydraulic-conductivity values from $3.0 \times 10^{-14}$ to $3.0 \times 10^{-13}$ m/s and a range of formation pressures from 75 to 105 psig as shown on Figures 5.3 and 5.4. The time period from the rapid pressure decline shown on Figure 5.2 to the second packer-inflation-pressure increase provided the best-fit simulation with a hydraulic conductivity of $1.0 \times 10^{-13}$ m/s and an apparent formation pressure of 90 psig. However, because of the pressure communication of zone #1 and zone #2, and/or possible packer compliance, the zone #1 pressure was maintained at a seemingly artificially high level after the second packer-inflation-pressure increase and the zone #2 pulse-injection test. The non-ideal pressure response of zone #1 during these periods could not be successfully simulated as shown on Figures 5.3 and 5.4. Coupled with the observed response of zone #2 to the zone #1 pulse-injection test, the results of the W782W zone #1 simulations must be considered uncertain.

The pulse-injection test of zone #2 began on July 20 when the pressure in zone #2 was increased by 108.3 psi. At the time of the pulse injection, the pressure in zone #1 increased by 27.7 psi, in zone #3 by 12.5 psi, and in the packer-inflation system by 16.8 psi. The pressure in zone #3 and in the packer-inflation system decayed after the injection but the zone #1 pressure increased about 6 psi in the first 1.5 hours of the test and was approximately stable for the remainder of the testing period.

Simulations were conducted for the analysis of the zone #2 pulse-injection test using a range of hydraulic-conductivity values from $3.0 \times 10^{-15}$ to $3.0 \times 10^{-14}$ m/s and estimates of formation pressure ranging from 120 to 160 psig (Figures 5.5 and 5.6). For the pulse-injection test, the best-fit simulation corresponds to a hydraulic conductivity of $1.0 \times 10^{-14}$ m/s and an apparent formation pressure of approximately 140 psig.

The pulse injection of zone #3 began on July 21 when the pressure was increased by 99.4 psi. The zone #3 pulse injection caused immediate pressure changes in zones #1 and #2, and in the packer-inflation system, but the pressures increased by less than 6 psi and dissipated within the first several hours of the test as shown on Figure 5.2. The initial shut-in period apparently responded to variations in the pressure of the packer-inflation system.

The zone #3 pulse-injection test was simulated using a range of 3 hydraulic-conductivity values from $3.0 \times 10^{-15}$ to $3.0 \times 10^{-14}$ m/s and estimates of apparent formation pressure from 120 to 160 psig (Figures 5.7 and 5.8). The best-fit simulations indicate a hydraulic conductivity of $1.0 \times 10^{-14}$ m/s and an apparent formation pressure of approximately 140 psig.

## 5.2 Borehole W805E

Borehole W805E was drilled in a silty mudstone bed of the lower unnamed member of the Rustler Formation (Section 4.2). Pulse-injection tests were performed in three packer-isolated intervals in borehole W805E from July 10 to July 15, 1987. Figure 5.9 shows the configuration of the multipacker test tool in W805E during of these tests.

Borehole W805E was left open after drilling and was exposed to atmospheric pressure for approximately 50 hours after drilling. The packers were inflated to approximately 500 psig at 0204 on July 11, and the test zones were shut in immediately following packer inflation. After shut in, the pressures in all of the test zones began rising. Figure 5.10 is a linear-linear sequence plot of the entire W805E testing period showing each pulse-injection test and the variations in packer-inflation pressure throughout the testing period.

The packer-inflation pressure was increased to approximately 500 psig after a 16-hour compliance period. During the compliance period, the inflation pressure declined approximately 150 psi. After the compliance period, the following pulse-injection tests were performed: a 94.7-psi pressure pulse was applied to zone #1 on July 11; a 105.1-psi pressure pulse was applied to zone #2 on July 13; and a 97.8-psi pressure pulse was applied to zone #3 on July 14.

The pulse-injection test of zone #1 began at 2001 on July 11. The pressure in zone #1 was increased by 94.7 psi during the injection. In addition to the test zone, only zone #2 and the packer-inflation system responded to the pulse, but the magnitude of these responses was less than 2 psi. The time of packer compliance coincided with the zone #1 pressure buildup due to shut-in conditions. Because most of the pressure buildup occurred during a period of significant packer-pressure change, the buildup curve was probably not representative of a pressure response due to formation conditions only. Therefore, the pressure-response data for the zone #1 shut-in period prior to the pulse-injection test were directly prescribed using a varying-pressure history sequence. The remaining portion of the test were simulated with a pulse sequence.

The simulations of the zone #1 pulse-injection test were developed using a range of hydraulic-conductivity values from $1.0 \times 10^{-14}$ to $1.0 \times 10^{-13}$ m/s and a range of apparent formation pressures from 210 to 240 psig as shown on Figures 5.11 and 5.12. The best-fit simulation was achieved with a hydraulic conductivity of $5.0 \times 10^{-14}$ m/s and an apparent formation pressure of 225 psig. The observed data were well matched by the simulation and the later portions of the zone #1 response were apparently unaffected by the subsequent tests on zones #2 and #3 and a second packer-pressure increase prior to the zone #2 test.

The pulse-injection test of zone #2 began on July 13 when the pressure in zone #2 was increased by 105.1 psi. At the time of injection, little change was noted in the pressures in zones #1 and #3 but the packer-inflation pressure increased by about 21 psi, about a 4% change.

The zone #2 pulse-injection test was simulated with a range of hydraulic-conductivity values from $3.0 \times 10^{-15}$ to $1.0 \times 10^{-14}$ m/s and estimates of formation pressure ranging from 120 to 160 psig (Figures 5.13 and 5.14). The best-fit simulation of the pulse-injection sequence was obtained with a hydraulic conductivity of $1.0 \times 10^{-14}$ m/s and an apparent formation pressure of approximately 140 psig.

The pulse-injection test of zone #3 began on July 14 when the pressure in zone #3 was increased by 97.8 psi. Little pressure change was recorded in zones #1 and #2 at the time of injection, and the packer-inflation pressure increased less than 5 psi.

The zone #3 pulse-injection test was simulated using a range of hydraulic-conductivity values from $3.0 \times 10^{-15}$ to $3.0 \times 10^{-14}$ m/s and estimates of formation pressure from 95 to 140 psig (Figures 5.15 and 5.16). The best-fit simulation for the zone #3 pulse-injection test indicates a hydraulic conductivity of $1.0 \times 10^{-14}$ m/s and an apparent formation pressure of 110 psig. The zone #3 measured response during the buildup period before the pulse-injection test appeared to be sensitive to other tests and packer-pressure increases.

5.3 Borehole W805SW

Borehole W805SW was drilled in a silty claystone bed of the lower unnamed member of the Rustler Formation (Section 4.2). Pulse-injection tests were performed in two packer-isolated intervals in borehole W805SW from August 26 to August 31, 1987. Figure 5.17 shows the configuration of the multipacker test tool in W805SW during these tests.

Borehole W805SW was left open after drilling and was exposed to atmospheric pressure for approximately 94 hours after drilling. Figure 5.18 is a linear-linear sequence plot of the entire W805SW testing period showing each pulse-injection test and the variations in packer-inflation pressure throughout the testing period.

The packers were inflated to approximately 520 psig on August 26, and the test zones were allowed to remain open to atmospheric pressure until approximately 1500 on August 27 to allow packer compliance to occur before the pressure buildup in response to shut-in conditions. All test zones showed positive increases in pressure following shut in. During the compliance and shut-in periods, the packer-inflation pressure declined by approximately 95 psi, to approximately 425 psi. Because of the relatively small decrease in the packer-inflation pressure and the apparent stabilization of the inflation pressure at the end of the compliance period, the packer-inflation-system pressures were not adjusted during the remainder of the testing period in W805SW. After the compliance period, the following pulse-injection tests were performed: a 102.9-psi pressure pulse was applied to zone #1 on August 28; and a 92.6-psi pressure pulse was applied to zone #3 on August 29. Because of access-time limitations in the WHS, only zones #1 and #3 were tested in W805SW. Therefore, the buildup-pressure response in zone #2 during the entire testing period was also analyzed to attempt to obtain an order-of-magnitude estimate of zone #2's hydrologic parameters.

The pulse-injection test of zone #1 began at 1800 on August 28 when the pressure in zone #1 was increased by 102.9 psi. The packer-inflation system also responded to the pulse injection in zone #1, and the response was less than 6 psi. The other test zones did not respond to the zone #1 test. Figure 5.18 shows that changes in packer-inflation pressure and the zone #3 pulse injection did not affect the fluid-pressure response in zone #1.

The simulations of the zone #1 pulse-injection test were developed using a range of hydraulic-conductivity values from $3.0 \times 10^{-15}$ to $1.0 \times 10^{-14}$ m/s and a range of formation pressures from 250 to 300 psig as shown on Figures 5.19 and 5.20. The best-fit simulation for the injection sequence indicated a hydraulic conductivity of $6.0 \times 10^{-15}$ m/s and an apparent formation pressure of 275 psig.

Time and access limitations prevented performance of a pulse injection test in zone #2 of borehole W805SW. To estimate the zone #2 hydrologic parameters, the entire test-period fluid-pressure response to the initial shut in was analyzed as a hydrologic test. The GTFM simulation of the pressure buildup after shut in of zone #2 in borehole W805SW was simulated using a prescribed zero-pressure preshut-in history sequence, and a pulse sequence for the entire testing period in the borehole. Although the pressure buildup appeared to be normal and free of any responses to other events, the observed data were not well matched by the simulation. The results of the analysis indicate a hydraulic conductivity in the range of $1.0 \times 10^{-13}$ m/s to $1.0 \times 10^{-14}$ m/s and an apparent formation pressure of greater than approximately 90 psig (Figures 5.21 and 5.22).

The pulse-injection test of zone #3 began on August 29 when the pressure in zone #3 was increased by 92.6 psi. During the pulse injection, less than a 0.5-psi change was observed in zones #1 and #2, and the packer-inflation pressure increased by 16.0 psi, a 4% change. The fluid-pressure response to the zone #3 pulse injection showed an initial rapid decline, followed by a slower rate of decline without an abrupt change in slope, as would be caused by an external influence or equipment failure. Also, approximately 12.5 hours after the pulse injection, the measured fluid-pressure response indicates a 2-hour buildup of approximately 8 psi followed by a slow decline in pressure until the end of the testing period. These changes in rates of pressure response could not be precisely simulated indicating that the responses may be somewhat anomalous. No explanation for these behaviors is evident, and similar behavior is not manifested in fluid-pressure responses in zone #1 or #2 during this time period.

The zone #3 pulse-injection test was simulated using a range of hydraulic-conductivity values from 1.0 x $10^{-14}$ to 1.0 x $10^{-13}$ m/s and estimates of formation pressure from 60 to 80 psig (Figures 5.23 and 5.24). The best fit to the early-time data before the anomalous rise in pressure was obtained using a hydraulic conductivity for zone #3 of 2.0 x $10^{-14}$ m/s, and an apparent formation pressure of approximately 70 psig.

5.4 Borehole W850W

Borehole W850W was drilled in the upper halite of the Salado Formation (Section 4.3). The contact of the Salado Formation with the Rustler Formation is at a depth of 844 feet in the WHS (see Figure 1.2). Pulse-injection tests were attempted in three packer-isolated intervals in borehole W850W from July 27 to August 3, 1987. Figure 5.25 shows the configuration of the multipacker test tool in W850W during these tests.

According to the driller's log, borehole W850W was producing water at approximately "0.25 gallons per minute" (Appendix A, Table A.8). During a posttest inspection of borehole W850W, this water production was observed and was determined to issue from a narrow discrete area on the upper half of the borehole, about 65 inches from the shaft wall. The water inflow was either from a discrete fracture or from the contact of the shaft's concrete liner with the halite of the Salado Formation. Borehole W850W was left open after drilling and was exposed to atmospheric pressure for approximately 72 hours after drilling. However, because of the water inflow, the borehole filled with water before installation of the test tool. Therefore, zones #1 and #2 were subject to a slight pressure due to the weight of the water in the borehole. Also, because the borehole filled with water of high salinity, the borehole was not refilled with brine before testing. Figure 5.26 is a linear-linear sequence plot of the entire W850W testing period showing each pulse-injection test and the variations in packer-inflation pressure throughout the testing period.

The packers were inflated to approximately 508 psig on July 28, and the test zones were shut in 30 minutes after packer inflation. The fluid-pressure responses for zones #2 and #3 showed immediate buildups after shut in, but the zone #1 pressure did not begin increasing until about 2 hours after shut in. Figure 5.26 also shows that pressures in zones #2 and #3 increased quickly and leveled off at 20 psig and 30 psig, respectively. Before the early 1987 grouting exercise in the WHS, a piezometer at depth level 834 indicated a pressure of approximately 25 psig at the shaft-liner-to-formation contact (Bechtel, 1986; see also Section 6.1 of this report). The presence of the flowing water at the shaft liner to formation contact in W850W, and the early pressure response of zones #2 and #3 indicates that these parts of the formation near the shaft may have had a different pretest pressure history from parts of the formation farther from the shaft wall. The almost-immediate zone #3 pressure buildup in response to the shut in was probably due to the fluid inflow at the shaft-liner-to-formation contact. The zone #2 response to shut in was similar to the zone #3 response, but the pressure buildup was slower and the shut in pressure was about 10 psi less than the zone #3 shut-in pressure. The shut-in response of zone #1 is different from that in zones #2 and #3, indicating that zone #1 probably had a different pretest pressure history than the other zones.

After the initial packer inflation, the packer-inflation pressure declined approximately 107 psi during a 17-hour compliance period. The packer-inflation pressure was then increased to approximately 494 psig, and an additional one-day compliance period resulted in an approximately 60-psi decrease in packer-inflation pressure. On July 29, the packer-inflation pressure was increased to 515 psig. After the second packer-inflation-pressure increase, the following pulse-injection tests were performed: a 97.6-psi pressure pulse was applied to zone #1 on July 30; a 90.4-psi pressure pulse was applied to zone #3 on July 31, but the test interval absorbed the pressure so quickly that a pulse test was not performed; and a 116.5-psi pressure pulse was applied to zone #2 on August 1.

The pulse-injection test of zone #1 began at 0001 on July 30 when the pressure in zone #1 was increased by 97.6 psi. Zone #2 and the packer-inflation system responded to the pulse injection within 30 seconds, but the magnitude of these responses was less than 7 psi. However, the fluid pressure in zone #2 continued to increase for 3.5 hours, reaching a maximum pressure increase in response to the zone #1 test of about 22 psi before decreasing. The zone #2 response to the zone #1 pulse injection indicates pressure communication between these two zones through the formation and/or through the test tool. The pulse-injection portion of the test was simulated with a pulse sequence. Figure 5.26 shows that the pulse-injection test of zone #2 caused a gradual 10-psi rise in pressure in zone #1 which then gradually decreased. This event ended the analyzable part of the zone #1 pressure response and is a further indication of pressure communication between zones #1 and #2.

The simulations of the zone #1 pulse-injection test were developed using a range of hydraulic-conductivity values from $3.0 \times 10^{-14}$ to

$3.0 \times 10^{13}$ m/s and a range of formation pressures from 30 to 50 psig as shown on Figures 5.27 and 5.28. The best-fit simulation of the zone #1 pulse injection was achieved with a hydraulic conductivity of $1.0 \times 10^{-13}$ m/s and an apparent formation pressure of 40 psig.

The pulse-injection test of zone #3 was not successful. The test zone included either a fracture in the formation or the shaft-liner-to-formation contact, and the pressure pulse could not be shut in before the peak pulse dissipated. Because of this rapid response, the proper conditions for a true pulse-injection test were not reached and the test was aborted. Figure 5.29 shows the fluid-pressure responses during the attempted test on zone #3.

The pulse-injection test of zone #2 began at 1530 on August 1 when the pressure in zone #2 was increased by 116.5 psi. Zone #1 and the packer-inflation system responded to the pulse injection within 30 seconds. A 19.2-psi increase was recorded for the packer-inflation system and a 2.2-psi increase was recorded in the zone #1 pressure. The zone #1 pressure response to the zone #2 pulse injection continued for about 12 hours, with the pressure increasing by about 10 psi before decreasing. The pulse-injection portion of the test was simulated with a pulse sequence.

The simulations of the zone #2 pulse-injection test were developed using a range of hydraulic-conductivity values from $3.0 \times 10^{-14}$ to $3.0 \times 10^{-13}$ m/s and a range of formation pressures from 30 to 50 psig as shown on Figures 5.30 and 5.31. The best-fit simulation of the zone #2 pulse injection was achieved with a hydraulic conductivity of $1.0 \times 10^{-13}$ m/s and an apparent formation pressure 40 psig, the same parameters as derived for the analysis of the zone #1 test.

5.5 Borehole W850SE

Borehole W850SE was drilled in the upper halite of the Salado Formation (Section 4.3). The contact of the Salado Formation with the Rustler Formation is at a depth of 844 feet in the WHS (see Figure 1.2). Pulse-injection tests were performed in three packer-isolated intervals in borehole W850SE from August 18 to August 25, 1987. Figure 5.32 shows the configuration of the multipacker test tool in W850SE during these tests. To avoid setting the multipacker tool near the shaft-liner-to-formation contact as had been done in W850W, an extension was added to the test tool to allow it to be set deeper in the borehole.

After drilling, the borehole was observed to be producing water and was capped between the drilling and testing periods. During the capped period, the inflowing fluid filled the borehole with brine and gas, and was observed to be under pressure during an inspection of the borehole between the drilling and testing periods. To incorporate this pretest period in the GTFM analysis, an estimate of the pressure in the capped borehole had to be derived. Following the testing in the WHS, caps with pressure gages were placed on the fluid-producing boreholes. During the month following the installation of the gage on W850SE, a pressure of about 30 psig was observed to build up in this borehole. This pressure was used for the fixed-pressure, pretest history sequences for the analysis of the pulse-injection tests in W850SE. Because of the inflow of saline water into the borehole, it was not necessary to fill the borehole with brine before inflating the packers. Figure 5.33 is a linear-linear sequence plot of the entire W850SE testing period showing each pulse-injection test and the variations in packer-inflation pressure throughout the testing period.

The test tool was installed on W850SE on August 18 and the packers were inflated to approximately 500 psig. The test zones were shut in approximately 5 hours after packer inflation. The measured pressures in zones #1 and #2 began increasing immediately after the zones were shut in. The zone #3 transducer was not recording at this time due to an electrical-cable malfunction, but the pressure recorded for zone #3 after repairing the cable indicated that the pressure in the zone probably began rising immediately after shut in.

The packer-inflation pressure was increased to approximately 521 psi after a 20-hour compliance period during which the packer-inflation pressure had declined approximately 100 psi. Beginning about one hour after the packer-pressure increase, the following pulse-injection tests were performed: 103.5-psi pressure pulse was applied to zone #1 on August 19; a 103.1-psi pressure pulse was applied to zone #2 on August 21; and a 100.7-psi pressure pulse was applied to zone #3 on August 22.

The pulse-injection test of zone #1 began at 2245 on August 19 when the pressure in zone #1 was increased by 103.5 psi. Zones #2 and #3 and the packer-inflation system responded to the pulse injection within 30 seconds, but the magnitudes of these responses were less than 1 psi in zones #2 and #3, and less than 8 psi in the inflation system. The time period from the mid-point of zone #1 drilling and the subsequent capping of the borehole to the time of the shut in of the zone (a time period including a brief period when the borehole was opened for a borehole inspection) was treated as a fixed-pressure history sequence, with a prescribed borehole pressure of 30.0 psig. The pulse-injection test was simulated with a pulse sequence. Figure 5.33 shows that events such as the pulse-injection tests of zones #2 and #3 had little effect on the fluid-pressure response in zone #1.

The simulations of the zone #1 pulse-injection test were developed using a range of hydraulic-conductivity values from $1.0 \times 10^{-14}$ to $1.0 \times 10^{-13}$ m/s and a range of formation pressures from 40 to 60 psig as shown on Figures 5.34 and 5.35. The simulations show that the early-time data were not as well matched as the later-time fluid-pressure response. The best-fit simulations indicate a hydraulic conductivity of $3.0 \times 10^{-14}$ m/s and an apparent formation pressure of 50 psig.

The pulse-injection test of zone #2 began at 2030 on August 21 when the pressure in zone #2 was increased by 103 psi. The fluid pressures in zones #1 and #3 increased by less than 2 psi, and the packer-inflation pressure increased by about 17 psi, about a 4% change. The time period from the mid-point of zone #2 drilling and the subsequent capping of the borehole to the time of the shut in of the zone (a time period which included a brief period when the cap was removed for a borehole inspection) was treated as a fixed-pressure history sequence with a constant borehole pressure of 30.0 psig. The pulse-injection test was simulated with a pulse sequence. Figure 5.33 shows that the late-time response of zone #2 was strongly affected by the pulse-injection test in zone #3. The fluid pressure in zone #2 increased by 9 psi in response to the zone #3 test and remained almost constant for the remainder of the testing period. There was no attempt to match these later time data during the modeling of the zone #2 test.

The zone #2 pulse-injection test was simulated using a range of hydraulic-conductivity values from $1.0 \times 10^{-14}$ to $1.0 \times 10^{-13}$ m/s and estimates of formation pressure ranging from 30 to 60 psig (Figures 5.36 and 5.37). The best-fit simulation indicated a hydraulic conductivity of $3.0 \times 10^{-14}$ m/s and an apparent formation pressure of about 45 psig.

The pulse-injection test of zone #3 began at 1630 on August 22 when the pressure in zone #3 was increased by 100.7 psi. Zone #1 experienced a pressure increase of less than 1 psi due to the zone #3 pulse injection, but the fluid pressure in zone #2 increased about 9 psi and stabilized at that level for the remainder of the testing period. The packer-inflation pressure increased by about 22 psi, about a 5% change. The GTFM simulation of the pulse-injection test in zone #3 in borehole W850SW was developed in a similar manner as that for the zone #2 test, and included the post-drilling period when the borehole was capped and pressurized. The pulse-injection test was treated as a pulse sequence.

The zone #3 pulse-injection test was simulated with a range of hydraulic-conductivity values from $1.0 \times 10^{-14}$ to $1.0 \times 10^{-13}$ m/s and estimates of formation pressure from 80 to 100 psig (Figures 5.38 and 5.39). The best-fit simulations indicate a hydraulic conductivity of $2.0 \times 10^{-14}$ m/s and an apparent formation pressure of 90 psig.

## 5.6 Borehole W1320E

Borehole W1320E was drilled in the Salado Formation (Section 4.4). The borehole was started in halite which was included in zone #3; crossed an anhydrite marker bed which was included in zone #2; and the last 18 feet were drilled in a polyhalite sequence which was included in zone #1. Pulse-injection tests were performed in three packer-isolated intervals in borehole W1320E from August 8 to August 17, 1987. Figure 5.40 shows the configuration of the multipacker test tool in W1320E during these tests.

Borehole W1320E was left open after drilling and was exposed to atmospheric pressure for approximately 14 hours. The packers were inflated to approximately 518 psig on August 8 and the test zones were shut in 10 minutes after packer inflation. The pressure in Zone #2 began increasing immediately after shut in, the pressure in zone #1 began increasing within 30 minutes, and the pressure in zone #3 began to increase about 4 hours after shut in. Figure 5.41 is a linear-linear sequence plot of the entire W1320E testing period showing each pulse-injection test.

The packer-inflation pressure was increased to approximately 502 psig after a 2-day compliance period during which the inflation-system pressure decreased by about 88 psi. After the compliance period, the following pulse-injection tests were performed: a 173.3-psi pressure pulse was applied to zone #1 on August 11; a second pulse-injection test was performed on zone #1 with a 50.0-psi pressure pulse on August 12; a 52.6-psi pressure pulse was applied to zone #2 on August 14; and 53.0-psi pulse pressure was applied to zone #3 on August 15. Figure 5.41 shows that after the second packer-pressure increase and following the zone #1 pulse injection, the packer-inflation pressure increased after each pulse-injection event and continued to rise during the response period of the pulse injection in zone #3. The final packer-inflation pressure at the end of testing was 612 psig.

Throughout the testing period, the fluid pressures in all zones exhibited stepwise pressure increases concurrent with each inflation and injection event. At the end of the testing period, the fluid pressures in all test zones were still rising as shown on Figure 5.41. Figure 5.41 also shows that the apparent formation pressure is probably greater than 500 psig. To perform truly representative pulse-injection tests with this formation pressure, a suitable injection pressure would be greater than 600 psig (Pickens and others, 1987). This range of injection pressures would require packer-inflation pressures of 800 to 1000 psig. Such pressures were not possible in this testing program for two reasons. First, these inflation and injection pressures were beyond the performance range of the transducers in the multipacker test tool and higher-range transducers were not available during the time allotted for the WHS testing. Second, using injection pressures of 600 psig or greater within 6 feet of the unlined shaft posed serious safety questions. If the injection pressure had exceeded the horizontal stress near the depressurized (since 1984) shaft wall, possible cracking and/or sloughing of the Salado Formation at the shaft wall could have occurred, possibly causing injury to personnel and damage to the WHS conveyance system. By keeping the injection pressure within safe limits, the resulting test results have a higher degree of uncertainty.

The testing period in zone #1 contained two pulse-injection tests conducted on successive days. The first pulse-injection test of zone #1 began at 1800 on August 11, when the fluid pressure in zone #1 was increased by 173.3 psi. Pressures in zones #2 and #3 and the packer-inflation system began increasing in response to the pulse injection within one minute. The magnitudes of these fluid-pressure responses were 19.7 psi in the inflation system, 9.8 psi in zone #2, and 1.5 psi in zone #3. On August 12, the packer-inflation-system pressure was increased by 100 psi to 604.5 psig in preparation for the second pulse-injection test. Pressures in all three test zones responded to the packer-pressure adjustment, with pressures in zones #1 and #3 increasing approximately 10 psi and the pressure in zone #2 increasing 40 psi. Following the packer-pressure adjustment, the second pulse-injection test of zone #1 began at 2145 on August 12 with a 50-psi fluid injection. Fluid-pressure responses to this injection were less than observed during previous events and none of these pressures increased more than 6 psi in the other test zones and the packer-inflation system. Figure 5.42 shows that events such as the packer-inflation-pressure increase and the tests of zones #2 and #3 had little effect on the fluid-pressure response in zone #1.

The simulations of the zone #1 pulse-injection tests were developed using a range of hydraulic-conductivity values from $5.0 \times 10^{-15}$ to $5.0 \times 10^{-14}$ m/s and a range of formation pressures from 500 to 600 psig as shown on Figures 5.42 and 5.43. The best-fit simulations were obtained for the later parts of the testing period, during the response to the second pulse injection. The apparent zone #1 hydrologic parameters are a hydraulic conductivity of $2.0 \times 10^{-14}$ m/s and a formation pressure of 550 psig. It should be noted, however, that the apparent formation pressure derived from this test analysis is uncertain because of the formation's low hydraulic conductivity and the inability to apply an appropriate pressure pulse.

The zone #2 pulse-injection test began at 1815 on August 14 when the pressure in zone #2 was increased by 52.6 psi. Zones #1 and #3 did not react strongly to the zone #2 pulse injection, and their fluid pressures increased by less than 4 psi. The packer-inflation pressure increased by 16.1 psi, about a 3% change.

The GTFM simulations of the pulse-injection test in zone #2 in borehole W1320E were developed using a 0.0 psig fixed-pressure history period for the pre-shut-in period, and a varying-pressure history sequence for the pretest period including the zone #2 responses to the zone #1 and zone #3 tests.

The zone #2 pulse-injection test was simulated with a range of hydraulic-conductivity values from 1.0 x $10^{-14}$ to 1.0 x $10^{-13}$ m/s and estimates of formation pressure from 425 to 475 psig (Figures 5.44 and 5.45). The early-time data provided the best-fit simulation with a hydraulic conductivity of 3.0 x $10^{-14}$ m/s and an apparent formation pressure of approximately 450 psig. However, as indicated earlier, these results are uncertain because of limitations on the upper limit of inflation and injection pressures.

The zone #3 pulse-injection test began at 1230 on August 15 when the zone #3 pressure was increased by 53 psi. The zone #3 pulse injection was felt most strongly in zone #2 which had a 6-psi pressure increase. The zone #1 pressure increased less than 1 psi, and the packer-inflation pressure increased 9 psi, about a 1.5% change.

The zone #3 pulse-injection test was simulated using a range of hydraulic-conductivity values from 1.0 x $10^{-14}$ to 1.0 x $10^{-13}$ m/s and estimates of formation pressure from 75 to 125 psig (Figures 5.46 and 5.47). The zone #3 observed data were not well matched by simulations generated with any one set of parameters. However, despite the lack of a good match, the analysis results show that zone #3, with an apparent formation pressure of 100 psig, is clearly depressurized with respect to zones #1 and #2, and has an approximate hydraulic conductivity of $3.0 \times 10^{-14}$ m/s.

## 5.7 Sensitivity Analysis

The GTFM analysis of pulse tests is an iterative procedure in which the parameters hydraulic conductivity and formation pressure are varied to simulate the fluid-pressure response in the test interval. The resulting simulations are compared to the observed data to arrive at the best possible match of observed and simulated data and thus determine best estimates of the tested formation's hydrologic parameters. The simulation procedure therefore includes a sensitivity analysis of these two parameters. The plots included in Sections 5.1 through 5.6 show the variability of the results using these two parameters and indicate the quality of the fit and the range of applicability of the results. Generally, the apparent hydraulic conductivity value is ± one-half order of magnitude and the final apparent formation pressure is about ± 15% of its probable value.

In the GTFM model, the parameter specific storage is calculated by the model from input data on compressibility and porosity of the formation, and the compressibility and density of the test-interval fluid. Most of these input data were not measured for the tests conducted in the WHS. The formation properties for the zones tested were assembled from the literature after examination of the cores from the borehole. The porosity and formation compressibility for the mudstone and claystone of the unnamed lower member of the Rustler Formation were taken from Touloukian and others (1981), and for the evaporite beds of the Salado Formation from Krieg (1984). Sodium-chloride brine was assumed to be the formation fluid in both the unnamed lower member and the Salado Formation and a 10-lb/gal, saturated sodium-chloride brine was the fluid used to fill the boreholes for testing and was also the injection fluid for the pulse-injection tests. The fluid properties for the 10-lb/gal brine used in the testing were taken from Earlougher (1977).

The specific-storage values calculated for the tests in the boreholes of the WHS are as follows:

| BOREHOLE | SPECIFIC STORAGE |
|---|---|
| W782W | $1.74 \times 10^{-6}$/m |
| W805E | $1.29 \times 10^{-5}$/m |
| W805SW | $1.29 \times 10^{-5}$/m |
| W850W | $6.39 \times 10^{-7}$/m |
| W850SE | $6.39 \times 10^{-7}$/m |
| W1320E | $3.72 \times 10^{-7}$/m |

Figures 5.48 and 5.49 show simulations which were determined from a range of specific-storage values from $1 \times 10^{-4}$/m to $1 \times 10^{-7}$/m for two sets of hydraulic-conductivity and formation-pressure data. The simulations were compared to fluid-pressure-response data from the zone #2 test in borehole W805E. A comparison of the figures shows that the changes in the value of specific storage can cause up to a one order-of-magnitude change in the estimated hydraulic conductivity and a 5 to 10% change in the apparent formation pressure. Assuming that the formation parameters used in the analyses of the WHS tests are representative of the formations tested, then the results derived from the analyses are assumed to be accurate to within ± one-half order of magnitude in hydraulic conductivity, and to within ± 10% of apparent formation pressure.

The values of hydraulic conductivity derived for the boreholes in the WHS are very low and probably at the testing limit using this type of equipment on natural formation materials. However, the reported values are conservatively high, because including equipment compliance in the analysis would lower the hydraulic-conductivity values.

Section 2.2 described the fluid-pressure response to variations in temperature when the multipacker test was examined for leaks and proper operation at the surface. Temperature data were collected using thermocouples in all test intervals during every pulse-injection test (see Figure 2.2; temperature data for all tests are found in Stensrud and others (1988)). Examination of all the temperature data revealed that after the one-day waiting period between packer inflation and the beginning of testing, there were no significant temperature variations in the test intervals during the pulse-injection tests. Similarly, comparison of the fluid-pressure responses and the observed temperatures did not indicate that the observed fluid-pressure responses were due to temperature related effects such as those reported in Pickens and others (1987). Figure 5.50 shows a typical temperature response of the 3 test intervals during testing, in this case borehole W805E. The largest change in temperature occurred in the first 24 hours as the test-tool and the test-fluid temperature equilibrated with formation conditions at the test depth. This same period is also the time of maximum packer-inflation-pressure decline in response to packer compliance. The major test-interval fluid-pressure response to changes in temperature probably occurred during this time and cannot be separated from the response to changes in packer-inflation pressure. Minor temperature changes also occurred in each test interval during pulse injection. The remainder of the temperature data reveals no significant variations and no correlation with fluid-pressure responses.

The last area of evaluation of the sensitivity of the results presented in Sections 5.1 to 5.6 concerns whether or not pretest data from the time of shut in to the time of any pulse-injection test were best included as prescribed pressures using varying-pressure history sequences or were simulated using pulse sequences and compared to the observed data in the same way as the test zone's fluid-pressure responses were compared to the simulated pulse-injection tests (see Section 3.0). Both methods of treating the pretest periods were employed for most of the tests in the

WHS boreholes, and the tests simulated using the varying-pressure history sequences provided the best fits to the observed data during the pulse-injection tests.

Figures 5.51 and 5.52 are examples of the quality of the matches in tests analyzed using simulations developed for both cases. Both examples show that differences in the final assumed values of hydraulic conductivity using both cases were negligible. The figures also show the difference in the final assumed values of formation pressure. The final value of formation pressure using a varying-pressure history sequence for the zone #2 post-shut-in-period response was 6% to 22% lower than that derived using a pretest pulse sequence to simulate the zone #2 post-shut-in-period response. Using variable-pressure history sequences for all pretest conditions instead of pulse sequences, differences in the apparent formation-pressure values in the test analyzed for the WHS were observed in the analysis results for the tests in boreholes W805E, W805SW, and W850W, and in the hydraulic-conductivity values for the tests in the W782W, W850E, and W805SW boreholes. The overall change to the final parameter values was 22% or less, and given the overall uncertainty of the tests results due to the low hydraulic conductivities of the formations tested, the non-ideal test conditions, and the length of time available for the tests, the differences in assuming either case are considered to be within the range of overall test uncertainty.

## 6.0 SUMMARY AND CONCLUSIONS

### 6.1 Test Results

The permeability-testing program for the WHS was designed to provide the plugging and sealing program with information on the distribution of hydraulic conductivity, the radial variation of formation pressure, and, possibly, the distribution of fractures at various radial distances from the wall of the WHS in parts of the lower Rustler and upper Salado Formations. To accomplish these goals, a series of sub-horizontal boreholes were drilled in the WHS at the 782, 805, 850, and 1320-foot depth levels below ground surface (BGS). Pulse-injection tests were performed in six of these boreholes using a multipacker test tool configured to isolate three test intervals, or zones, in each borehole tested. After installing the multipacker test tool, the packers were inflated with the test zones vented to the atmosphere to dissipate the pressure created in the test zones by the expansion of the packers and the consequent compression of the test-zone fluid. After inflating the packers, the test zones were shut in. The shut-in periods, which were of varying length because of the constraints of other crews' work and shaft-access schedules, were followed by a series of pulse-injection tests in the isolated intervals. The deepest zone in each borehole, or zone #1, was the first zone tested, followed by either zone #2, the center zone, or zone #3, the zone closest to the shaft wall.

Shut-in fluid-pressure responses varied from hole to hole, and from zone to zone within boreholes as shown on the sequence plots for each borehole (Figures 5.2, 5.10, 5.18, 5.26, 5.33, and 5.41). The sequence plots also show that the early parts of the shut-in periods were characterized by relatively large decreases in the packer-inflation pressure. The decreases in packer-inflation pressure were primarily due to packer compliance as the packers expanded during the initial inflation. Temperature may also have had a minor role in the initial packer-inflation pressure decrease. The fluid-pressure increases during the shut-in periods of the test zones were often accelerated by pulse-injection tests in adjacent zones. This sympathetic response may have been due to a combination of packer compliance and the very low hydraulic conductivities of the rocks being tested. The pressure increases in the test zones in some cases caused pressure increases in the other zones. This effect was probably due to physical movement of the packers as the pressure increased in the test zones. The same effect was noted in some boreholes in response to increases in the packer-inflation pressure. Because of the low hydraulic conductivities of the units tested, these responses to pulse-injection and packer-inflation-pressure increases amounted to low-magnitude pressure pulses on the fluids in the test zones.

The extent and magnitude of these possible effects of packer compliance are unknown at this time. Some preliminary analysis indicates that the effects are important, but do not dominate the observed fluid-pressure responses in the test zones. Without additional testing as recommended in Section 6.2, these effects are not quantifiable.

The pulse-injection tests were analyzed using graph-theoretic-field-modeling (GTFM) techniques. The GTFM model can incorporate the effects of the pretest pressure histories of the test intervals into model simulations of the fluid-pressure response to the pulse injections. The simulations were compared to the observed test data. The analyses were performed in an iterative manner for ranges of hydraulic conductivity and apparent formation pressure to obtain a best-fit match of the model simulations and the observed data.

The GTFM analysis is based on the assumption that the formation pressure is constant over the length of the interval being tested and that no significant head gradient exists in the formation test interval. The decrease in formation pressure caused by the WHS has created a pressure-drawdown cone that is likely approximately symmetric around the shaft and which extends to a presently unknown distance into the formation. The shape of that drawdown cone is not well defined and it can be assumed to be developed somewhat differently in materials with different hydrologic properties. The results from the pulse-injection tests at the 850-foot depth level indicate that the depressurization at this level extends far enough into the formation so that the formation pressure is apparently the same for all the test-zone responses simulated with GTFM. The depressurization profiles at all test levels, including the 850-foot level, were assumed to be at steady-state during the individual test periods. The assumption of a constant, average formation pressure over the length of the test zones adds additional uncertainty to the modeled results.

The test analyses presented in Section 5 vary from simulations with good matches between observed data and simulated results to those tests in which the observed data were not well matched by the simulations. With the exception of boreholes W782W and W1320E, the zone #1 responses in each borehole were relatively easier to match than the zone #2 and zone #3 tests. The most likely reason for this pattern is that because of the scheduled work activity in the WHS, sufficient time was not available after each pulse-injection test to allow a complete recovery and stabilization period before the next pulse-injection test. Increased elapsed time between tests can often result in data sets which more closely represent true formation responses and are more likely to be better simulated by model solutions.

Table 5.3 lists the magnitude of the pressure pulse injected into each test zone. The magnitude of the pulse indicates the pressure increase above the measured pressure immediately before the start of the pulse-injection sequence. According to Pickens and others (1987), the pressure at the start of a pulse-injection test must be substantially different from both the pretest pressure and the formation pressure to allow a confident determination of hydraulic conductivity or permeability. In the tests conducted in the WHS boreholes, all the tests except those in borehole W1320E (see Section 5.6) and in the tests in zone #1 in W805SW and W805E achieved that objective.

The sequence plots of the test sequences (Figures 5.2, 5.10, 5.18, 5.26, 5.33 and 5.41) show that, according to the criteria presented in Pickens and others (1987), the pulse tests in zone #1 of W805SW and W805E, and all the tests in W1320E had less-than-adequate pressure pulses. The analyses and observed data for the W805E, W805SW, and W1320E tests indicate that actual formation pressures were not directly measured and the pressures were still building at the end of testing. Because of the slow response to shut in in zone #1 of W805SW, the pressure following the pulse was substantially higher than the pretest pressure, but substantially lower than the apparent formation pressure determined by the test analysis. In zone #1 in W805E, the pressure pulse was greater than the shut-in pressure at the time of testing, but slightly less than the apparent formation pressure. In zones #1 and #2 in W1320E, safety considerations, coupled with the lack of 0- to 2000-psig transducers necessary to monitor the elevated pressures at this depth, prevented raising the pressure to the greater than 500-psig pressure necessary to test these zones more accurately. The apparent formation pressures determined by the analysis for zones #1 and #2 in W1320E are probably lower than actual pressures. The progression in the apparent formation pressures from an underpressurized zone #3 near the shaft wall to increasingly higher pressures in zones #2 and #1 is probably representative of the actual progression in the magnitudes of formation pressures. However, testing limitations related to available time for testing and the pressure range of the pressure transducers prevented collection of a data set representative of actual in situ pressure conditions.

Table 5.3 summarizes the test results for all of the boreholes. Figure 6.1 is a graphic illustration of the formation-pressure profile. The data and the plots show that in each borehole there is a general lowering of pressure near the shaft wall at the test depths. The depressurization extends to about 1-1/2 shaft diameters at the 850 depth level. Apparent pressure communication between zones at the 782 depth level prevents, without further testing, determination of the pattern of depressurization at this level. Because the test-zone pressures were climbing at a significant rate at the end of testing in zone #1 at the 805 and 1320 depth levels, the observed test data appear to indicate that the actual formation pressures may increase to pressures approximating undisturbed, pre-shaft formation pressures at distances greater than one shaft diameter from the shaft. At both levels, however, the actual magnitude of that formation pressure cannot be determined from the available data.

The certainty of the formation-pressure estimates determined by the GTFM analysis of the borehole tests in the WHS is subject to inherent limitations. The tests were of relatively short duration considering the apparently low hydraulic conductivities of the formations tested. Also, many of the zones tested exhibited significant rates of pressure increase near the end of the testing periods after incomplete recovery to the pulse-injection tests. To estimate the reasonableness of the apparent formation pressures determined from the analysis of the WHS borehole tests, the formation-pressure estimates presented in Table 5.3 were compared to recent drill-stem tests of the Rustler Formation in well H-16 by Beauheim (1987; see also Stensrud and others, 1988). These tests indicate a formation pressure at the center of the Culebra, which is at 712.5 feet BGS at H-16 as compared to 718 feet BGS in the WHS, of approximately 160 psig; and a formation pressure at the center of the unnamed lower member of the Rustler, which is at 810 feet BGS in H-16, of approximately 260 psig. These pressures indicate a pressure gradient of

1.08 psi/ft which was used to estimate formation pressure for the upper three test horizons as follows:

| Depth Level (feet BGS) | 782 | 805 | 850 |
|---|---|---|---|
| Estimated Pressure (psig) | 230 | 250 | 300 |

Borehole tests conducted from holes drilled in the Salado Formation from rooms and drifts at the repository horizon (2130 feet BGS) indicate a formation pressure of 1200 to 1450 psig (Peterson and others, 1987). Comparing these estimated formation pressures to that estimated for the unnamed lower member (260 psig) indicates a pressure gradient of 0.71 to 0.90 psi/ft. Using these gradients, the formation pressure at the 1320 depth level is estimated to be 625 to 730 psig. Given the potential uncertainty of the formation-pressure estimates determined from the GTFM analyses, a comparison of the formation-pressure estimates from H-16 and from the GTFM analysis of the WHS borehole tests (Table 5.3 and Figure 6.1) indicates the following:

- The mudstone of the unnamed lower member at the 782 depth level appears to be depressurized at greater than one shaft diameter from the shaft wall. However, it could also be true that, because of the low hydraulic conductivity indicated for zone #1, a representative estimate of formation pressure was not possible.

- The siltstone of the unnamed lower member at the 805 depth level appears to have an undisturbed formation pressure at greater than one shaft diameter from the shaft wall.

- The formation pressure from zone #1 in borehole W1320E indicates that, at this depth, the Salado Formation may be slightly underpressurized at greater than one shaft diameter from the shaft wall. However, because the pressure was continuing to rise at the end of the zone #1 test period, the formation-pressure estimate of

550 psig probably underestimates the formation pressure of the Salado at this depth and the formation may not be underpressurized.

The source of the apparent underpressure observed in zone #1 at the 782 depth level is unclear. The pressures in zones #2 and #3 are similar and in the range of depressurization within one shaft diameter of the shaft wall as observed in the other boreholes tested. Examination of the sequence plot in Figure 5.2 shows that the pressure in zone #2 increased about 12 psi during the zone #1 pulse injection and the zone #2 pressure continued to rise for the remainder of the test. Zone #1 also increased about 30 psi during the zone #2 pulse injection. While packer compliance cannot be ruled out as the cause of these sympathetic pressure increases, the most likely cause of the apparent depressurization in zone #1 in borehole W782W is pressure communication around the packer, or through the formation. It is also possible that a local fracture near zone #1 intersects either the Culebra or the shaft-liner-to-formation contact where shaft-wall piezometers indicate pressures similar to the zone #1 test results.

At the 850-foot level, water and gas were observed flowing in the borehole. Here, the upper Salado appears to be depressurized to almost 2 shaft diameters from the shaft wall relative to the extrapolated formation pressure of approximately 300 psig. The pretest history period used for the analyses of the pulse-injection tests in W850SW includes the data on the pressure buildup due to water and gas inflow between the drilling and testing of that borehole (see Section 5.4). The amount of pressure buildup indicated by the pressure gage installed on the cap placed on borehole W850W after testing supports the conclusion that the 30- to 70-psig range of apparent formation pressures indicated by the analyses is appropriate for formation conditions at the time of testing. Therefore, the upper Salado appears to have been depressurized relative to the other geologic units tested. If the Rustler-Salado contact zone is relatively transmissive at this location, and if it has been draining to the key of the shaft liner since its installation in 1984, this drainage could be the source of the depressurization. As indicated on Figure 6.2, pressure-transducer data from the WHS piezometer #211, installed at level 834 just above the Rustler-Salado contact, also appear to show depressurization relative to piezometers in the Culebra and at the 758 depth level in the unnamed lower member of the Rustler Formation. (The piezometer data reported in Bechtel (1986) are data from pressure transducers installed in the concrete liner of the WHS, to monitor any pressure buildup behind the liner. The transducer installations were originally called piezometers by the WIPP-site contractors. For a complete discussion of these pressure-transducer installations see Appendix G in Haug and others (1987).) The WHS-piezometer data support the assumption that depressurization has occurred in the area of the shaft key, although the exact mechanism for this depressurization is unclear.

Figure 6.2 provides a graphic illustration of the fluctuations in pressure and the degree of pressure communication at the shaft-liner-to-formation contact at various depth levels in the WHS. The data show that flutua- tions in pressure are greatest at the Culebra depth level, and that significant fluctuations also occur at level 758 in the unnamed lower member of the Rustler. Figure 6.2 also shows that some pressure fluctuations occur simultaneously at all levels. This pressure communication indicates either direct communication between the geologic units along the shaft-liner-to-formation contact, or pressure communication through fractures or cold joints in the concrete liner. The magnitude of the pressures recorded by the transducers also indicates the degree of depressurization existing at the various depth levels instrumented. As mentioned earlier, these data corroborate the results of the pulse-injection testing that show the most depressurization along the shaft-liner-to-formation contact has occurred near the Rustler-Salado contact zone in the key area of the concrete liner.

Figure 6.3 graphically illustrates the variation of the hydraulic-conductivity values determined by the borehole tests in the WHS both as a function of depth and as a function of distance from the shaft wall. Figure 6.3 shows that all rocks tested have low hydraulic conductivity. Most of the reported values range from $1.0 \times 10^{-14}$ to $5.0 \times 10^{-14}$ m/s, with only 4 values falling outside that range. In W850W, the borehole with actively flowing water, the analyses indicated a slightly higher hydraulic conductivity. Considering the test conditions and the uncertainty surrounding the packer-compliance effects of the test tool, the range of one order of magnitude in hydraulic conductivity indicates that, essentially, all the zones and geologic units tested have similar, and low hydraulic conductivities.

The zones tested did not appear to indicate any enhanced permeability near the shaft in test intervals that may have been affected by the excavation of the WHS. In W850W, however, the zone #3 test was unsuccessful because the test interval included either an open fracture or a discontinunity at the concrete liner-formation contact and could not be tested by pulse injection. Therefore, hydraulic conductivity for this zone is significantly higher than found in the other test zones of this and other boreholes. Inspection of the borehole indicated that the liner-formation contact is the most likely channel for the relief of pressure in zone #3 in W850W, and that high permeability is probably not representative of the formation in this portion of W850W.

Because of the design of the test tool, and the space requirements of the WHS conveyance system, the test tool could not be configured to test more of the near-shaft parts of the formation in the boreholes from 0.0 to 5.4 feet from the shaft wall. This situation limited the ability to test the shaft-liner-to-formation contact in many of the boreholes. However, examination of the cores recovered from the boreholes did not reveal any open fractures in the near-shaft-wall parts of the boreholes. The possible pressure communication in zone #1 in borehole W782W is probably, if it exists in the formation, a local phenomenon at a greater distance from the shaft wall than could be expected from the influence of the excavation techniques. While no fractures attributable to drilling and blasting of the WHS were observed in the mudstones and halites in the tested boreholes, more brittle rocks such as the Magenta and Culebra dolomites could have experienced more construction-induced fracturing. However, the depth levels for testing were specifically chosen because of their significance in the plugging and sealing program, and not as part of a general WHS testing program, thus precluding testing of the Magenta and Culebra.

In summary, the following conclusions may be drawn from the permeability tests conducted in the boreholes drilled in the WHS:

1. The formation pressures determined by GTFM are uncertain because they were derived from relatively short tests in rocks with low hydraulic conductivity. The pressures can, therefore, be referred to as apparent formation pressures. Given the uncertainties as to their magnitudes, the results of all the test analyses nonetheless appear to indicate a pattern in which the formation pressures generally increase moving from the WHS into the formations. The near-shaft parts of the boreholes are probably depressurized because of the presence of atmospheric pressure in the shaft itself.

2. Considering the discussion in (1) concerning the magnitudes of the apparent formation pressures, these apparent formation pressures appear to increase with depth from land surface except where the tested formation has undergone significant depressurization, such as at the 850 depth level, and in the zones within one shaft diameter, as measured radially from the shaft wall.

3. The halite of the upper Salado at the 850 depth level has been depressurized relative to the test zones above it.

4. Water and gas were produced from either discrete fractures or the concrete-liner-to-formation contact in both boreholes at the 850 depth level. A small amount of water was produced from one of the boreholes at the 805 depth level.

5. The hydraulic conductivities of the mudstone, claystone, and evaporite beds are low and range from $6.0 \times 10^{-15}$ to $1.0 \times 10^{-13}$ m/s. A potentially important but not well understood factor concerning the uncertainties of the hydraulic-conductivity determinations is the effect of compliance of the multipacker test tool on the fluid-pressure responses measured during testing.

6. No direct evidence of fracturing due to the excavation techniques used in constructing the WHS was observed in the cores of the mudstone and claystone of the lower unnamed member, or in the bedded halite and other evaporite layers of the Salado Formation.

## 6.2 Recommendations

Two important recommendations are suggested from the results of the permeability-testing program conducted in the WHS at the WIPP site:

1. The design and function of the multipacker test tool should be thoroughly reviewed to determine whether or not design modifications are warranted. In particular, the effect of packer compliance on test results needs to be thoroughly evaluated in order to better understand and interpret the fluid-pressure responses obeserved during testing. In conjunction with the testing of the multipacker test tool, each packer in the inflation system should be configured to allow their pressures to be individually measured. The individual pressure measurements would aid in determining the degree and influence of equipment compliance and any apparent test-zone to test-zone communication.

2. More time should be allowed to conduct each test. This extra time should be used to:

a) allow packer-inflation pressures to stabilize for a longer period before the initial shut in;

b) allow a closer approach to formation pressures during the initial buildup period following initial shut in;

c) allow a longer recovery period for each test so as to more closely approach formation pressure in the test zone, and pressure stabilization in adjacent zones;

d) repeat tests when necessary, especially when pressure communication between test zones is indicated; and

e) shift the position of the multipacker test tool, if necessary, to include areas closer to the shaft wall, or areas where fractures are suspected to cause pressure communication.

If possible, future test programs could also include testing of the Culebra and Magenta dolomites in boreholes drilled from a shaft. By testing formations whose hydraulic properties are already well defined at other nearby locations, more confidence could be placed on both the testing and analysis methodologies.

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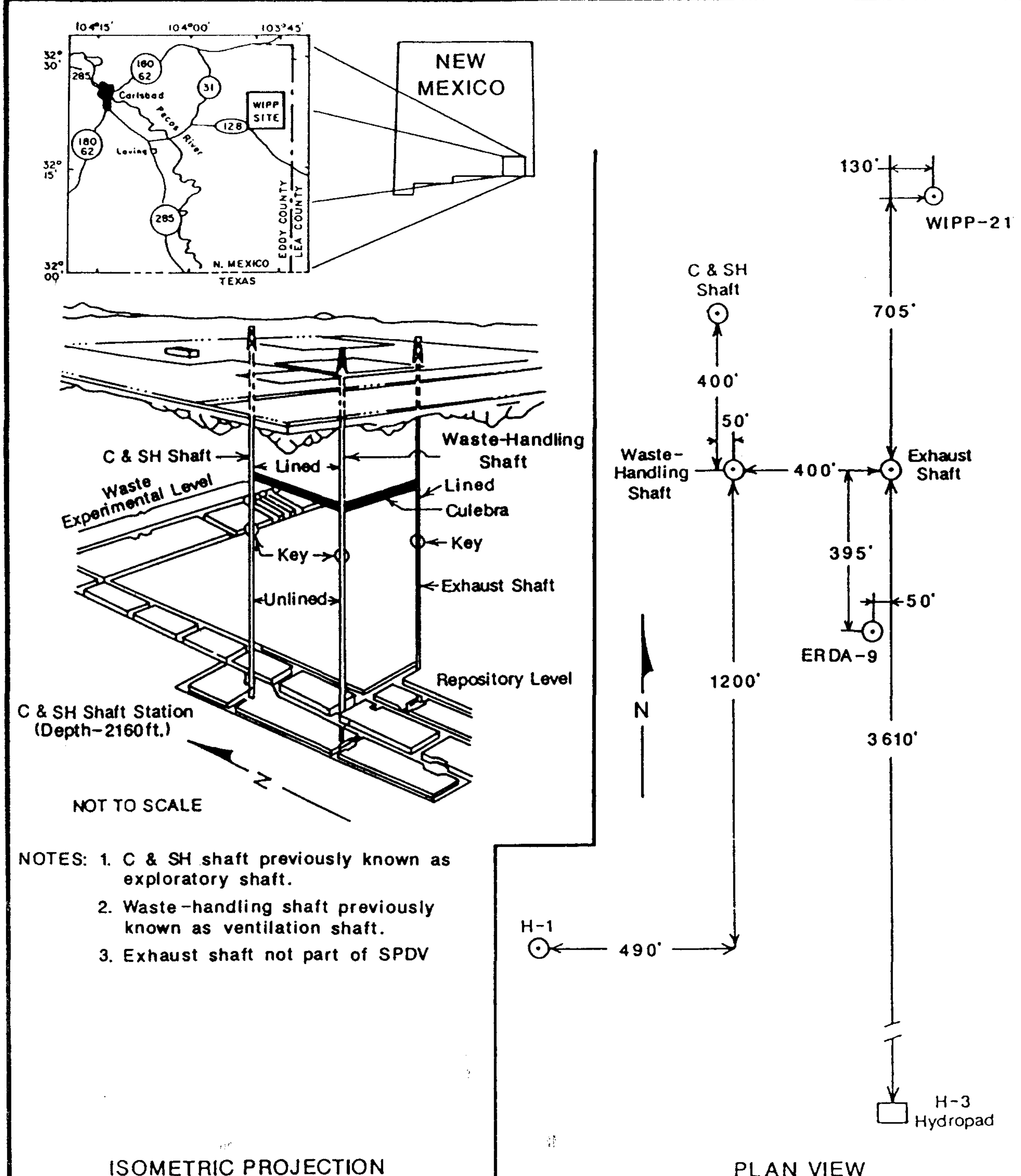


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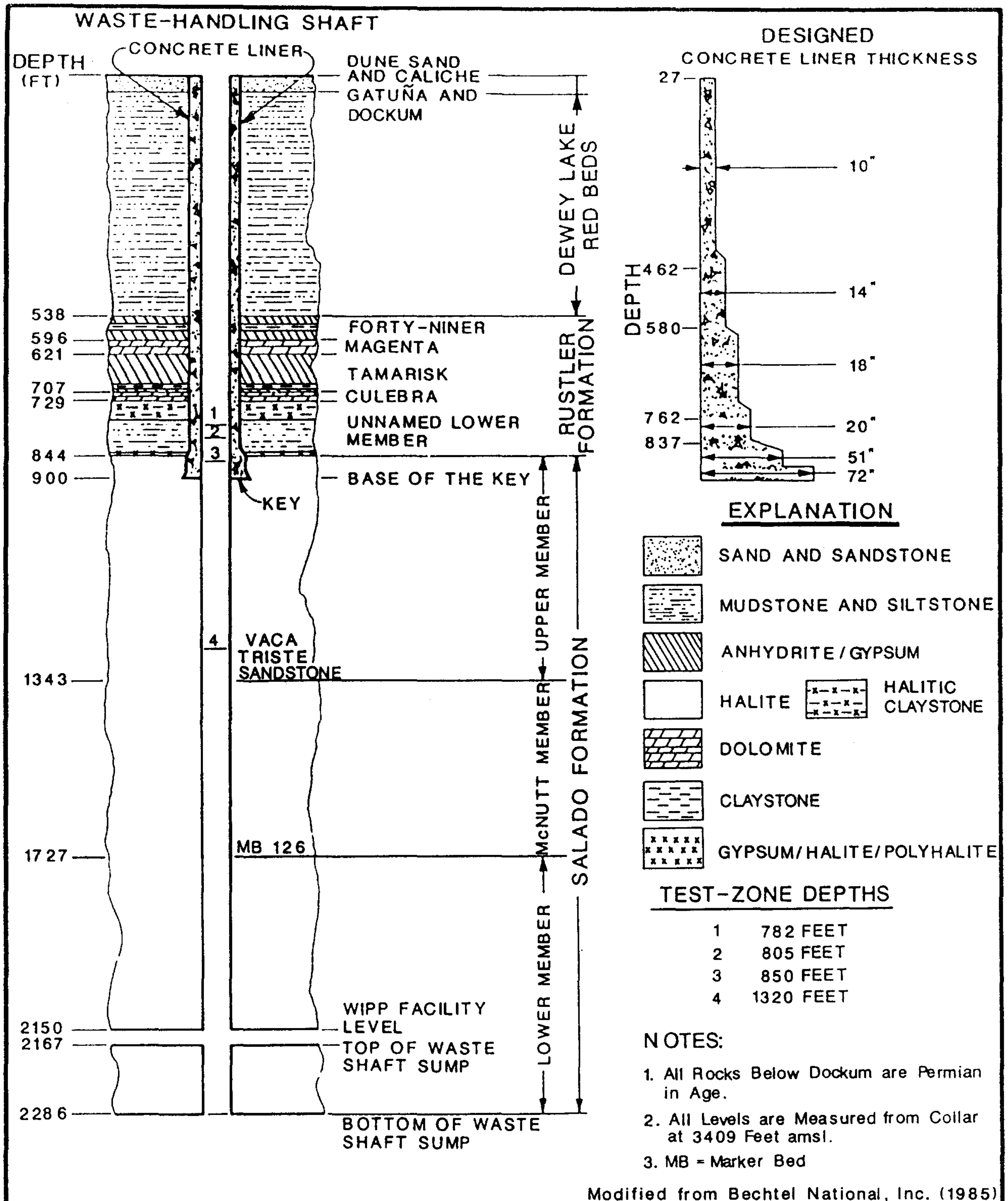
Locations of the Shafts at the WIPP Site
(Modified from Bechtel, 1985)

INTERA Technologies

Figure 1.1




| Drawn by | Date | Generalized Stratigraphy in the Waste-Handling Shaft Showing the Test Zones and the Concrete-Liner Thickness Profile |
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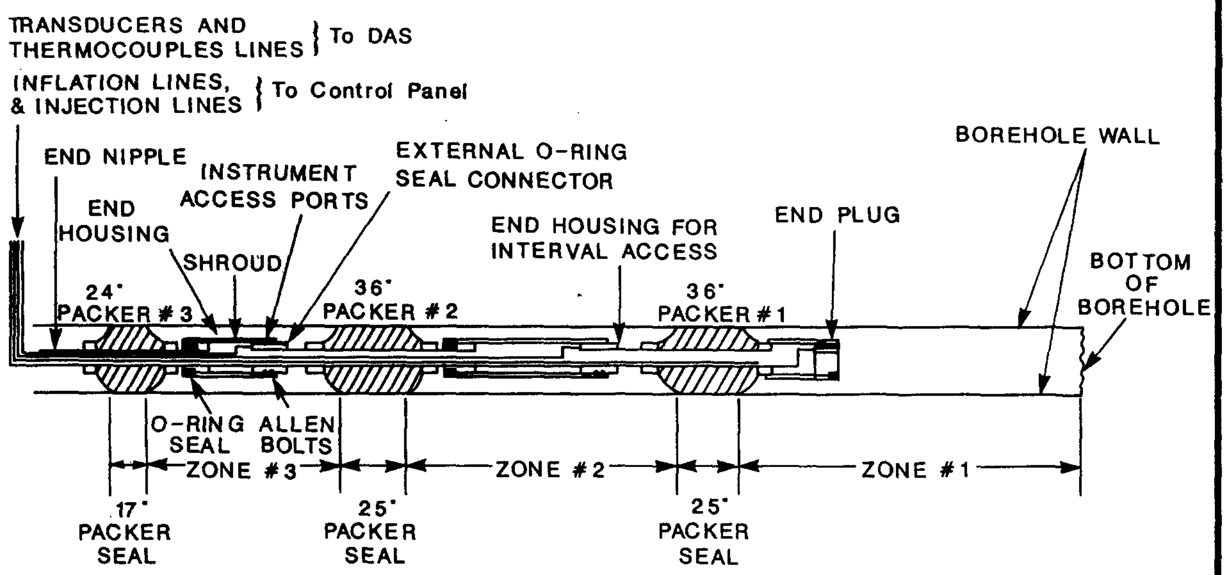
INTERA Technologies

Figure 1.2

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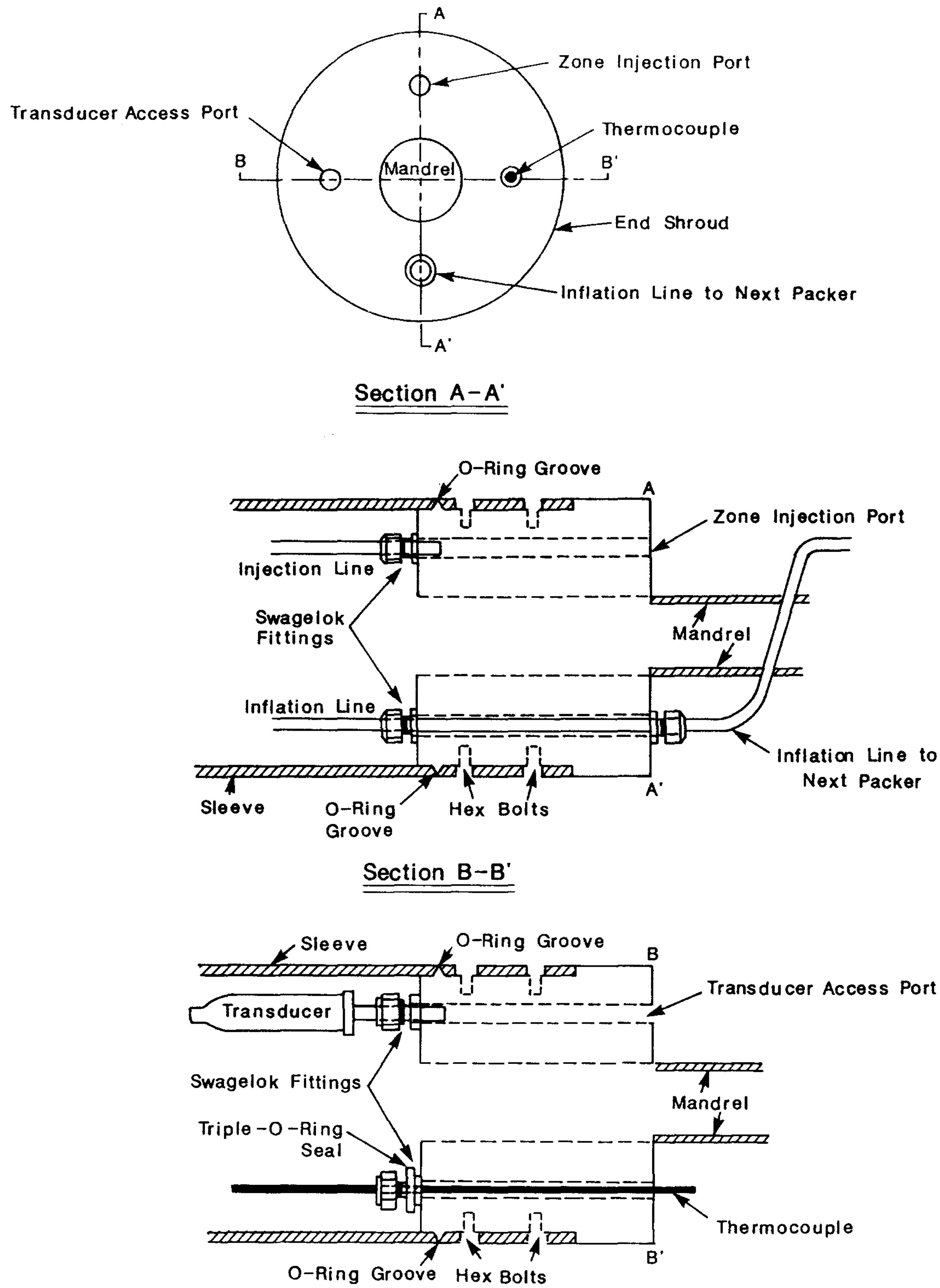
INTERA Technologies

Multipacker Test Tool Configured With 3 Packers for Pulse-Injection Testing in the Boreholes Drilled in the Waste-Handling Shaft

Figure 2.1




| Drawn by | Date | Spacer/Shroud End Showing Sensor Access to the Test Zones |
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| Revisions | Date | |
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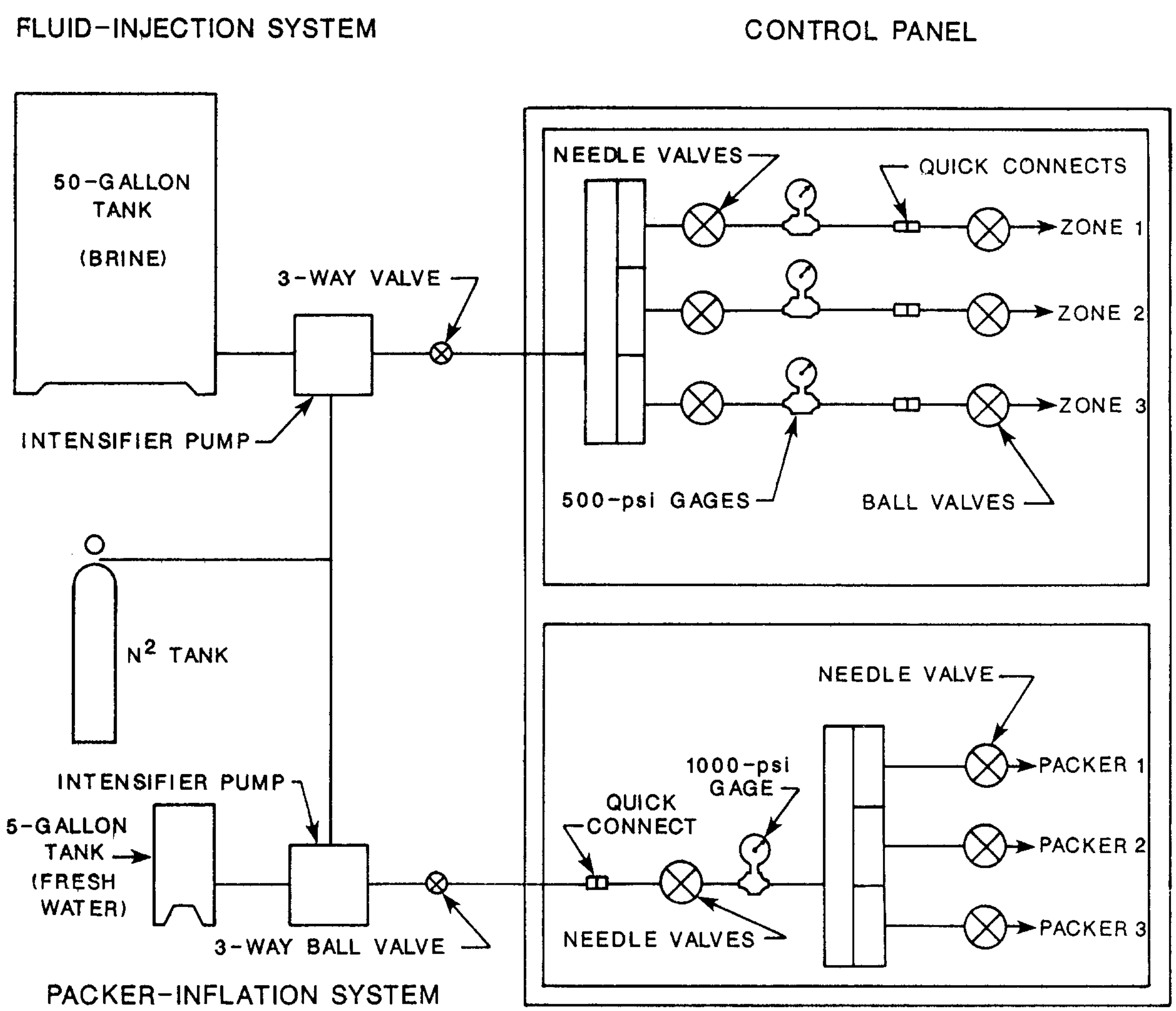
| INTERA Technologies | | Figure 2.2 |

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| Checked by | Date | |
| Revisions G.S. | Date 6/17/88 | |
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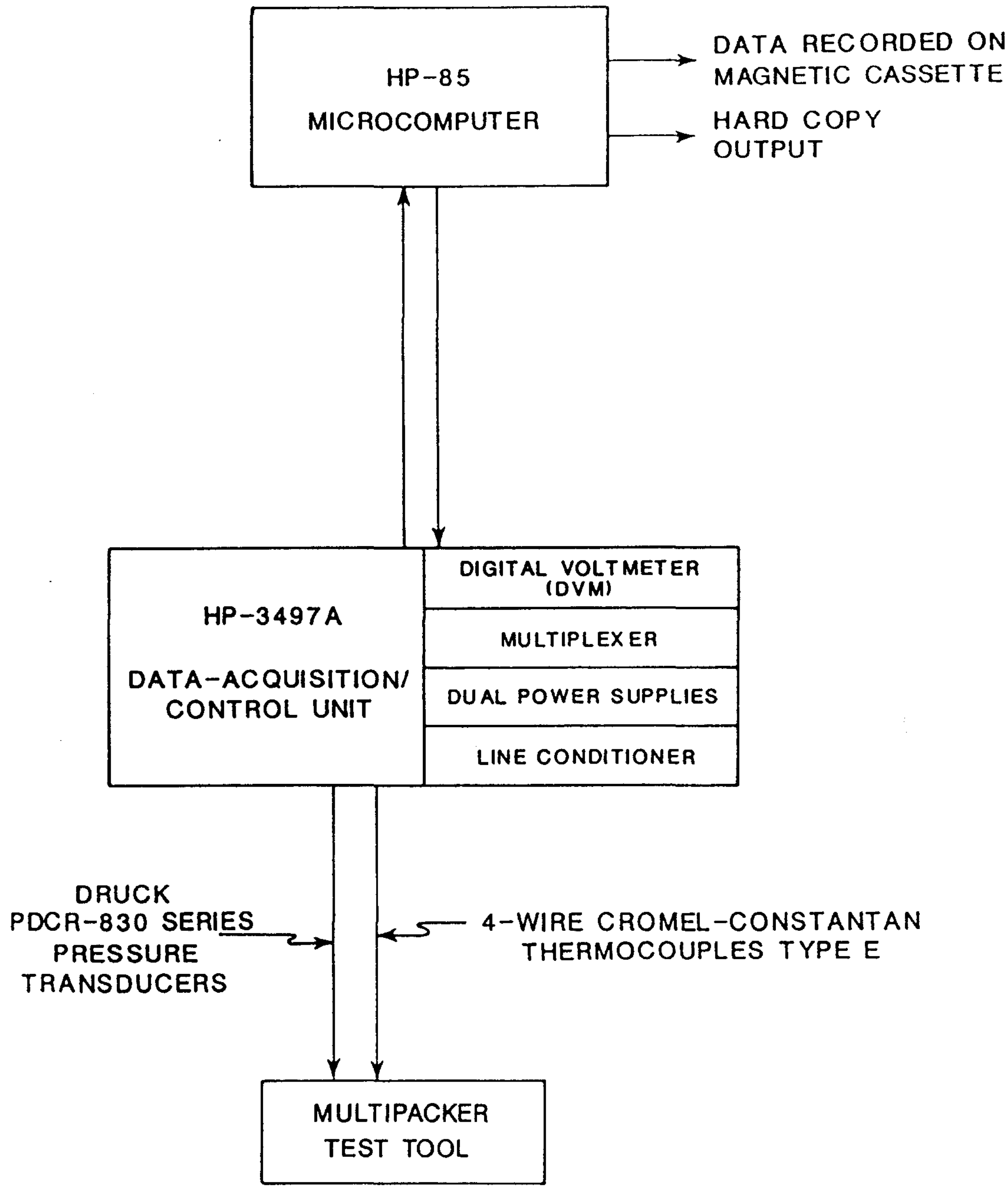
| INTERA Technologies | | Figure 2.3 |

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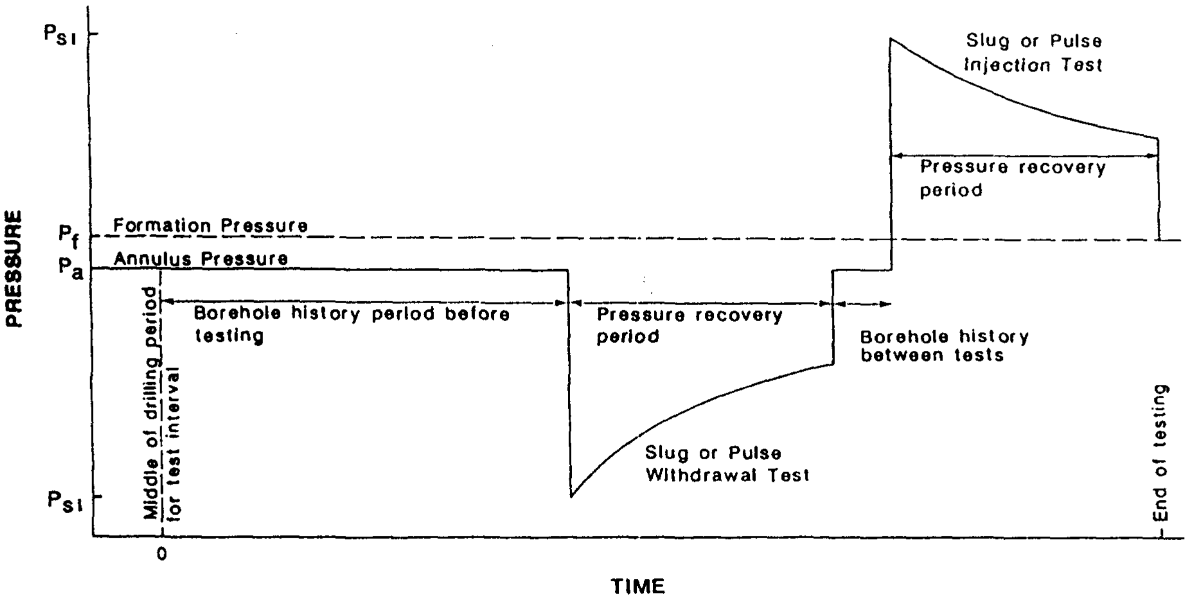
INTERA Technologies

Schematic Illustration of the Data-Acquisition System (DAS)

Figure 2.4




$P_f$ = Formation Pressure

$P_{si}$ = Pulse or Slug Pressure

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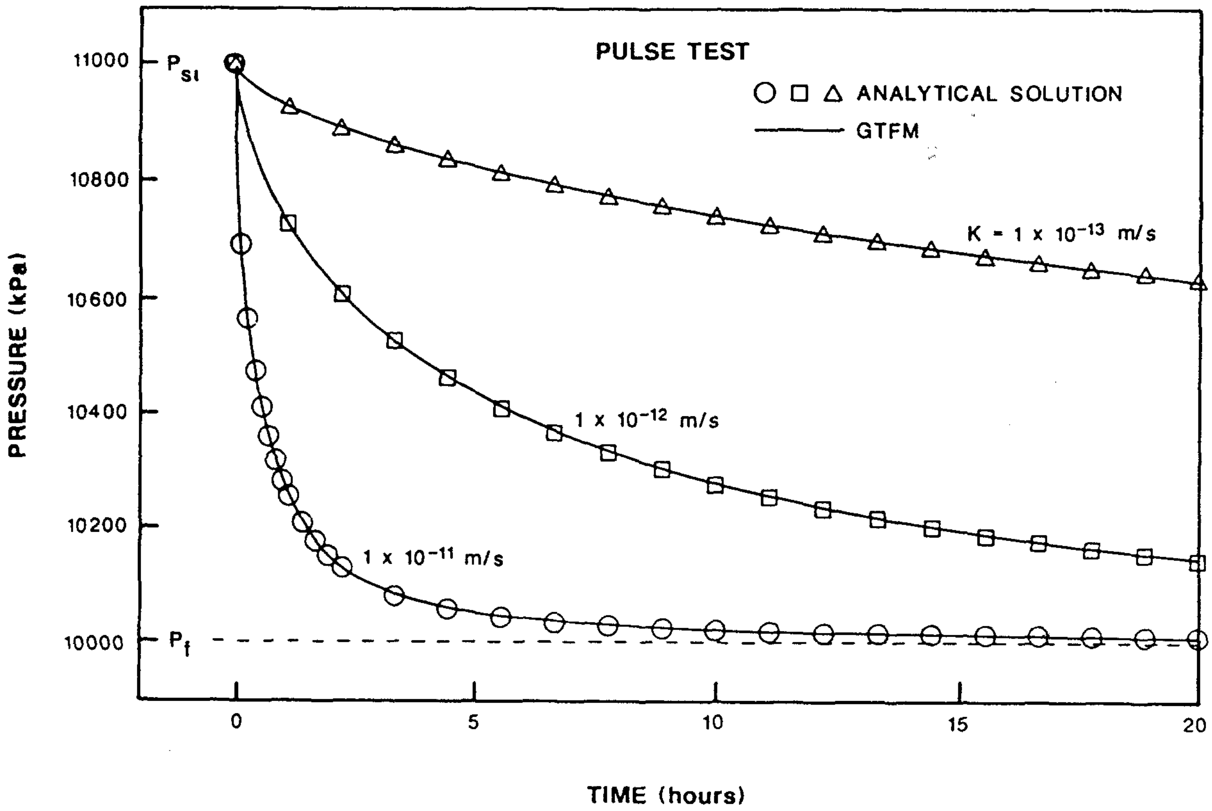
Schematic Illustration of the Borehole Pressure History that Develops During a Testing Sequence

INTERA Technologies

Figure 3.1




$P_f$ = Formation Pressure

$P_{si}$ = Pulse Pressure

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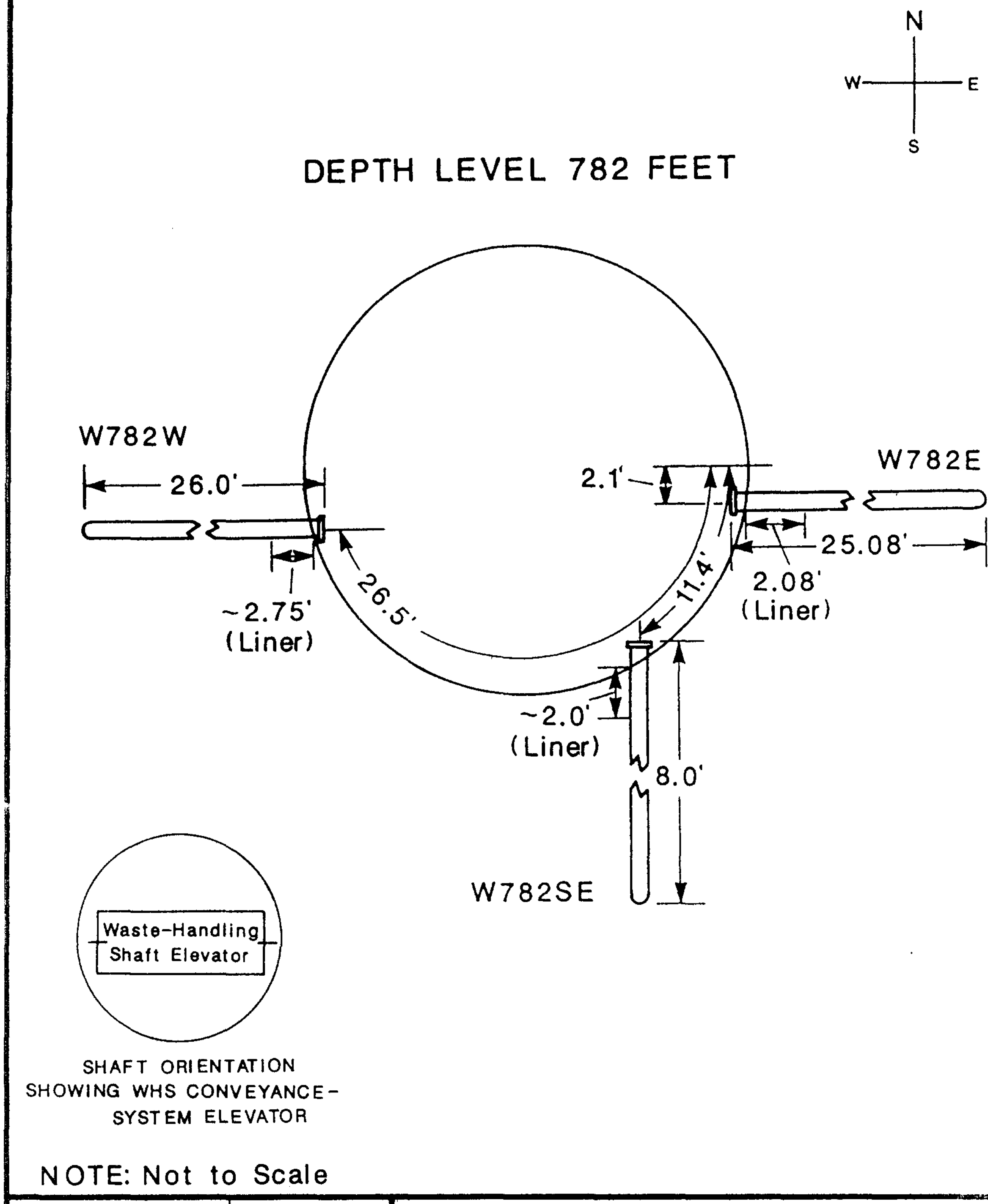
INTERA Technologies

Comparison Between GTFM and Bredehoeft and Papadopulos (1980) Analytical Solution Results

Figure 3.2




| Drawn by | Date | Locations and Orientations of Boreholes Drilled at the 782-Foot Level in the Waste-Handling Shaft |
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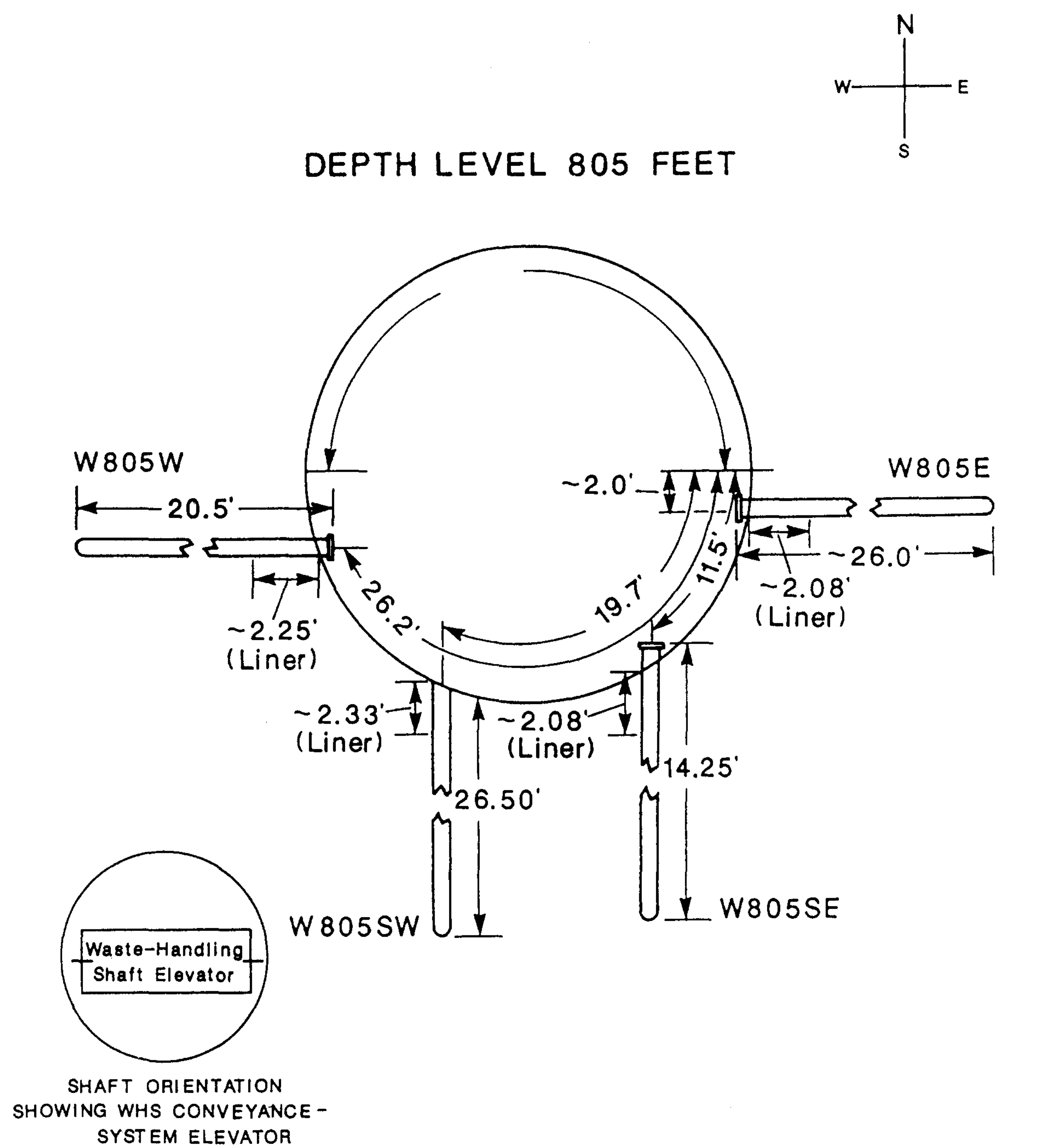
| INTERA Technologies | | Figure 4.1 |




NOTE: Not to Scale

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| Drawn by | Date | Locations and Orientations of Boreholes Drilled at the 805-Foot Level in the Waste-Handling Shaft |
| Checked by | Date | |
| Revisions | Date | |
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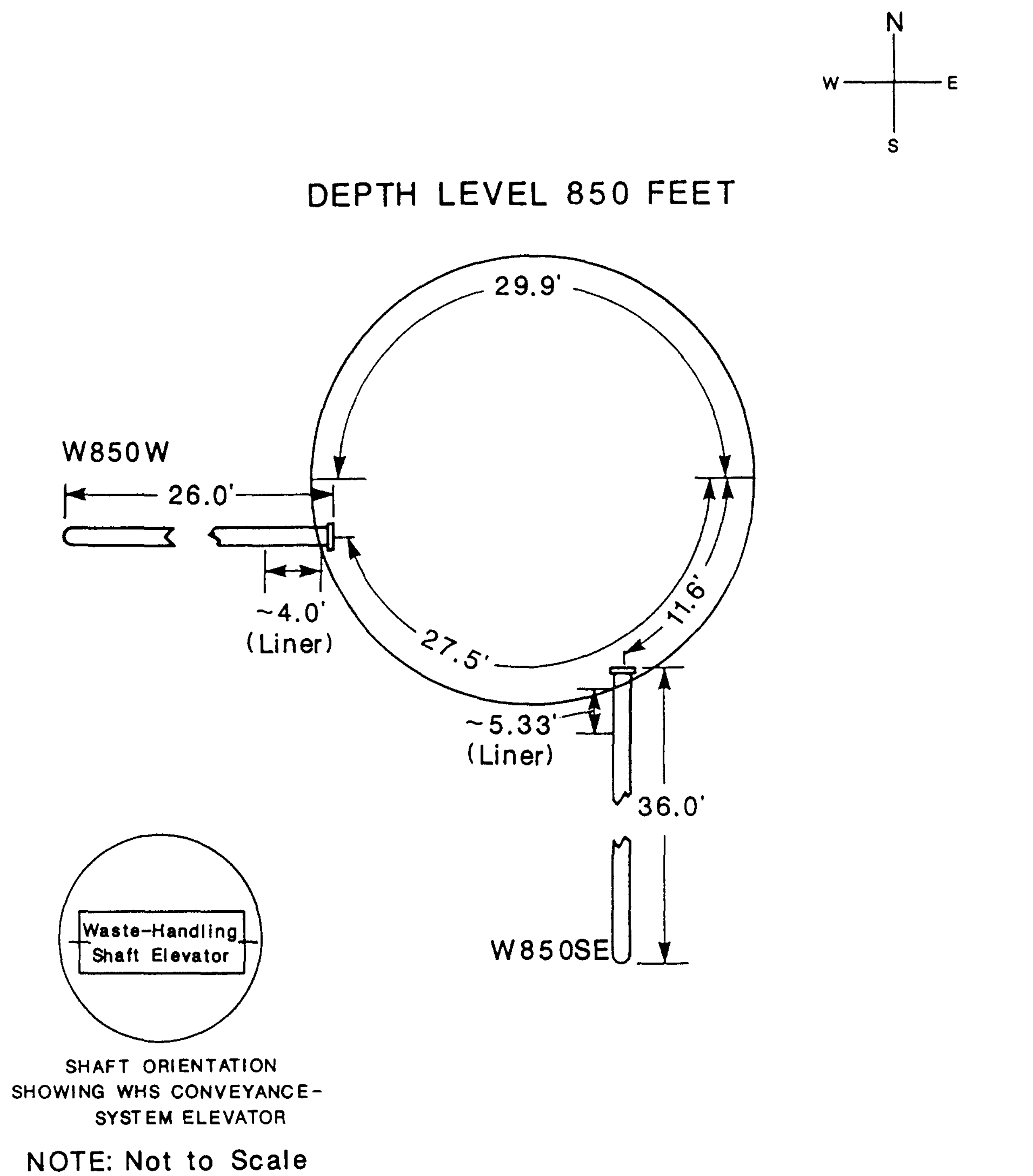
| INTERA Technologies | | Figure 4.2 |

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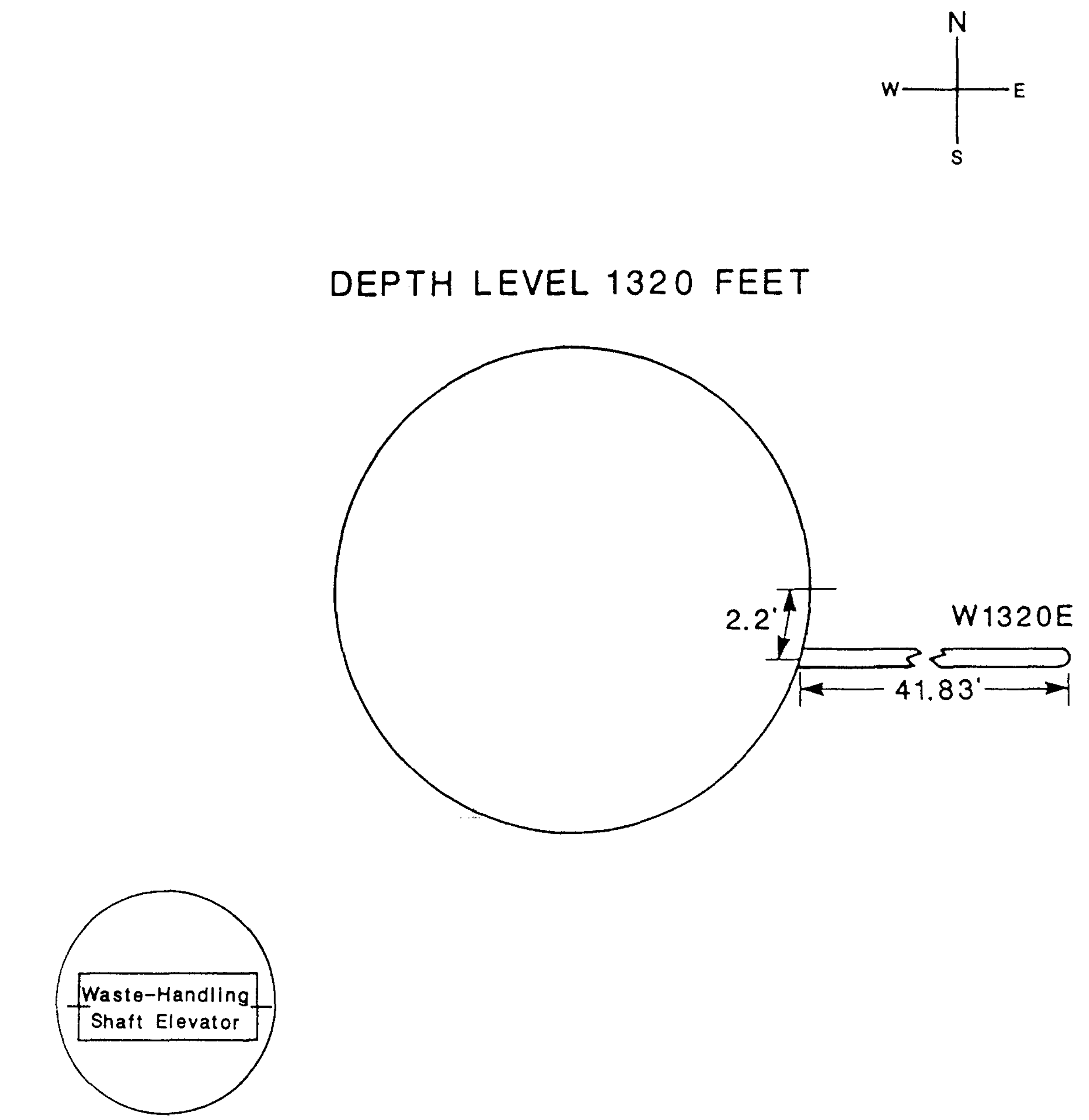
| INTERA Technologies | | Figure 4.3 |




SHAFT ORIENTATION
SHOWING WHS CONVEYANCE-
SYSTEM ELEVATOR

NOTE: Not to Scale

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| Drawn by | Date | Location and Orientation of the Borehole Drilled at the 1320-Foot Level in the Waste-Handling Shaft |
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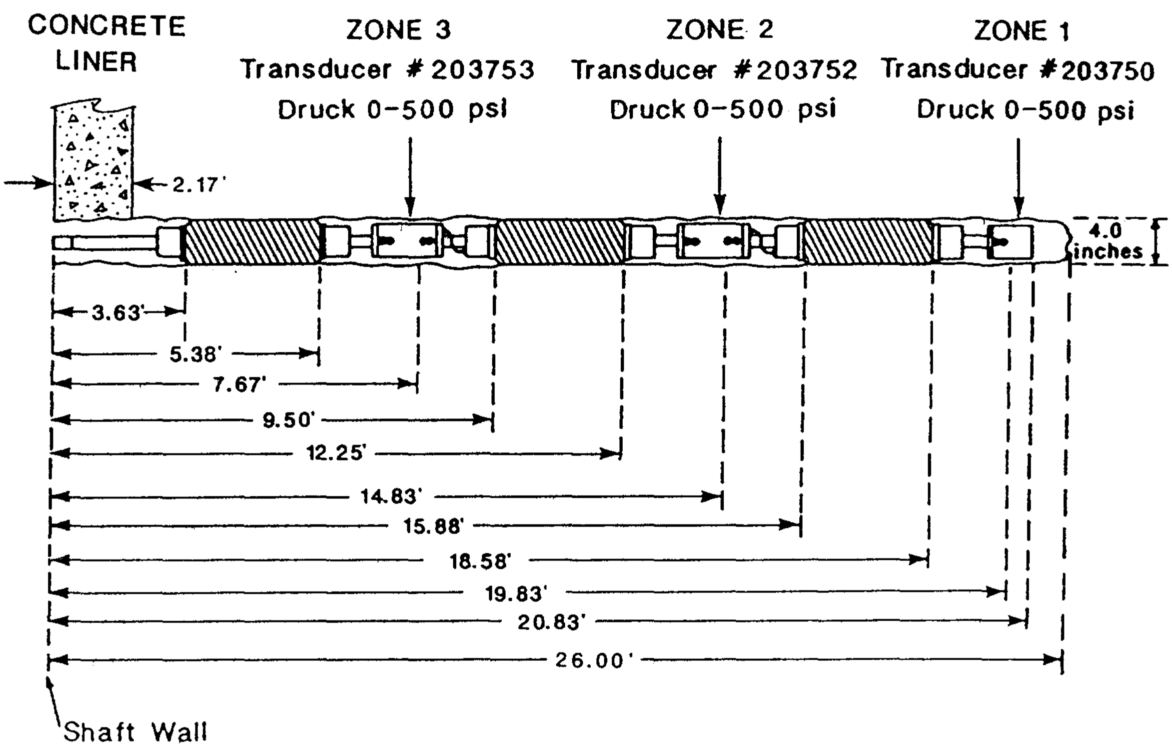
| INTERA Technologies | | Figure 4.4 |

SHAFT LEVEL: 782 feet BGS

BOREHOLE LOCATION: W782W (West Wall)

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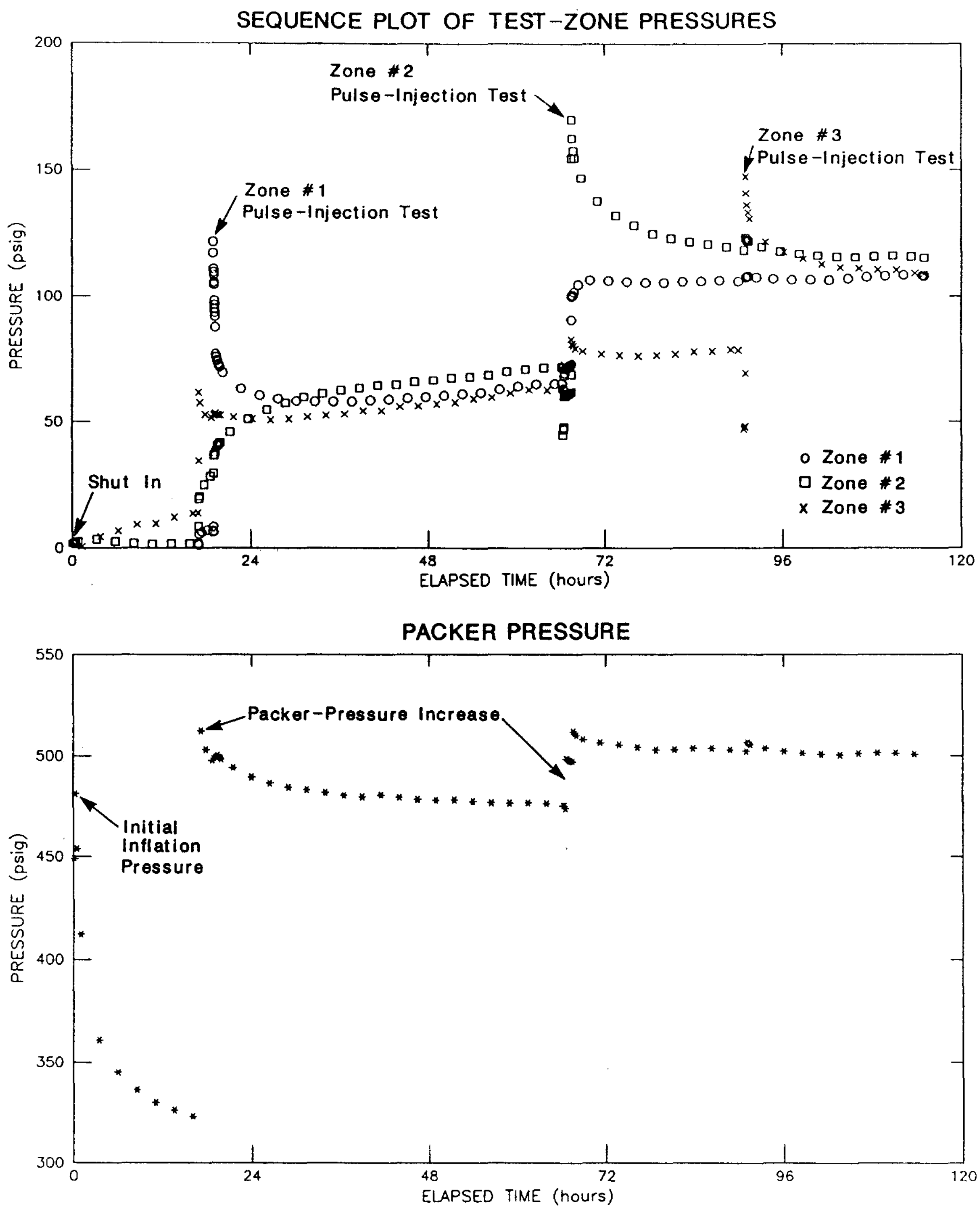
| INTERA Technologies | | Figure 5.1 |

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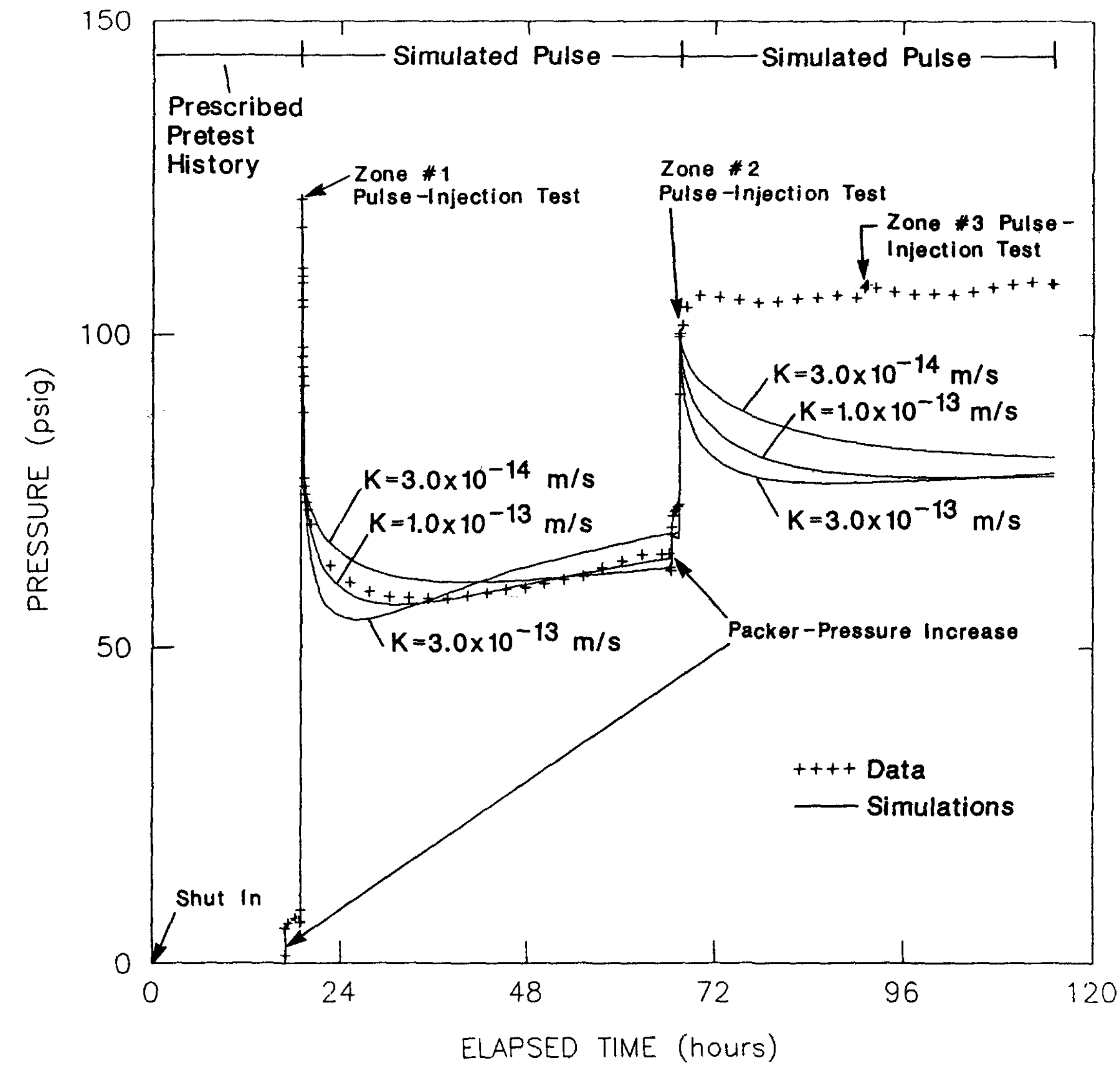
Linear-Linear Sequence Plot of the Test-Zone and Packer-Inflation Pressures During Testing in Borehole W782W

INTERA Technologies

Figure 5.2

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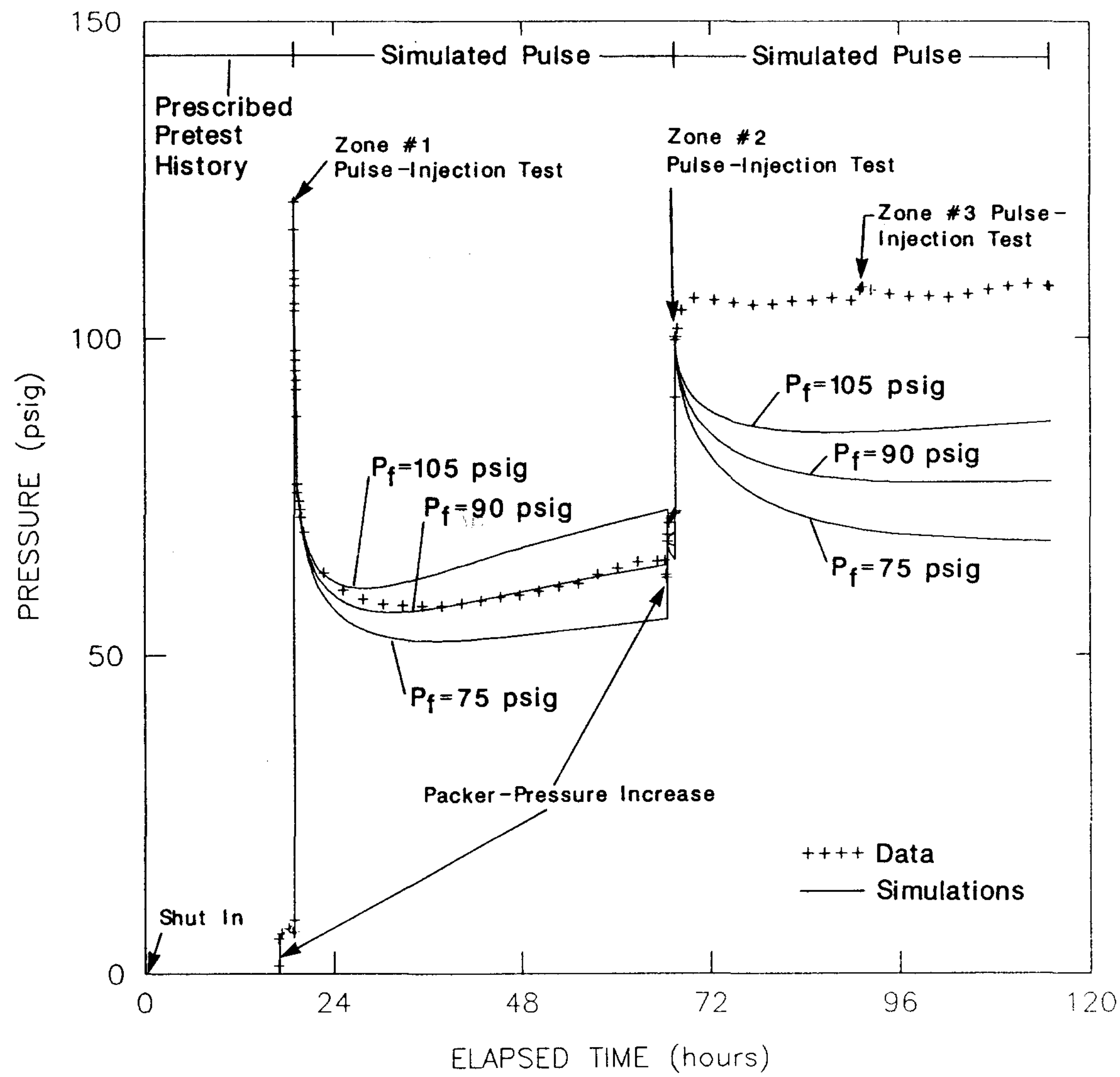
| INTERA Technologies | | Figure 5.3 |

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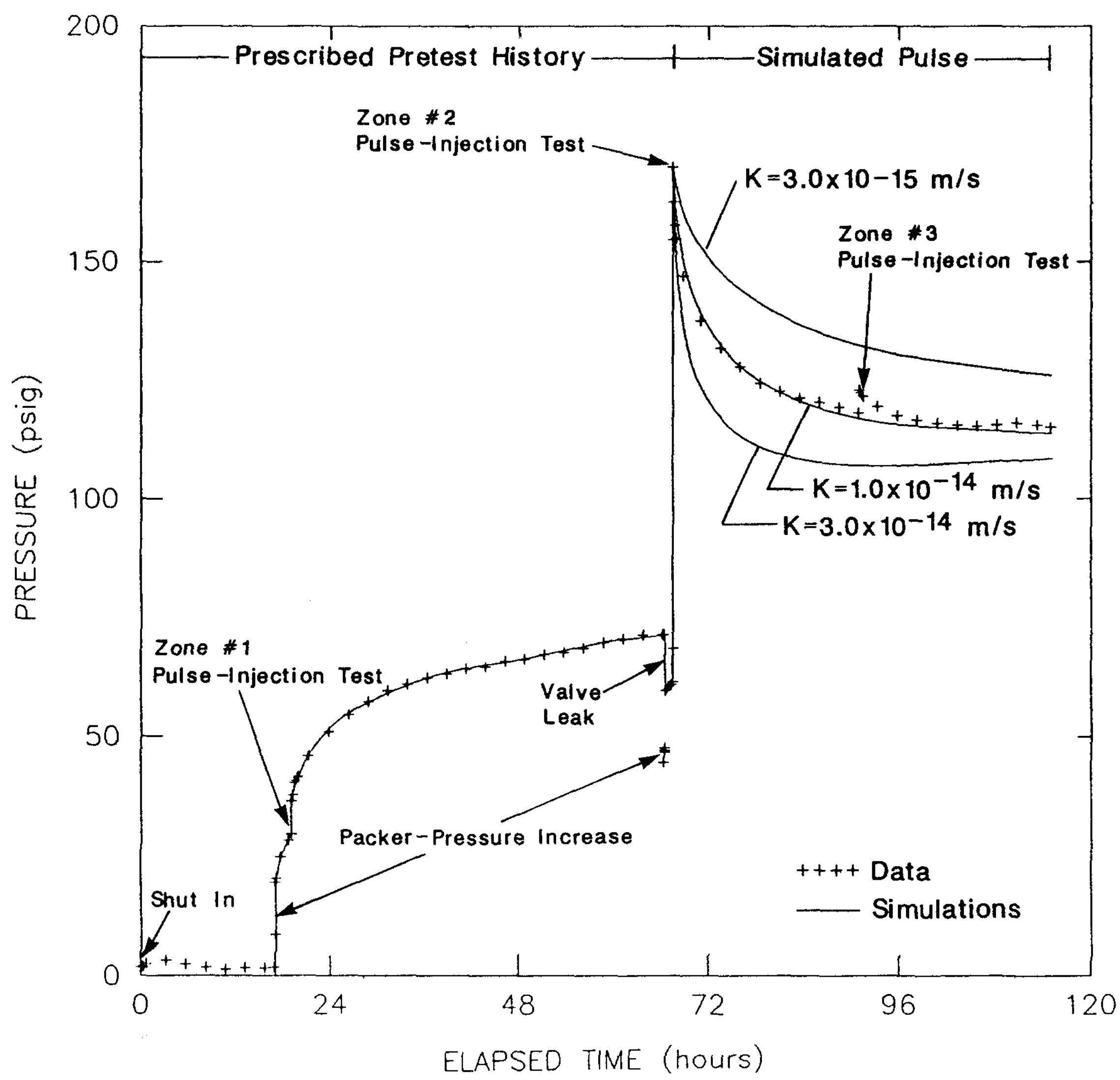
| INTERA Technologies | | Figure 5.4 |




| Drawn by | Date | Simulation of the Borehole W782W Zone #2 Pulse-Injection Test; Formation Pressure = 140 psig and Varying Hydraulic Conductivity |
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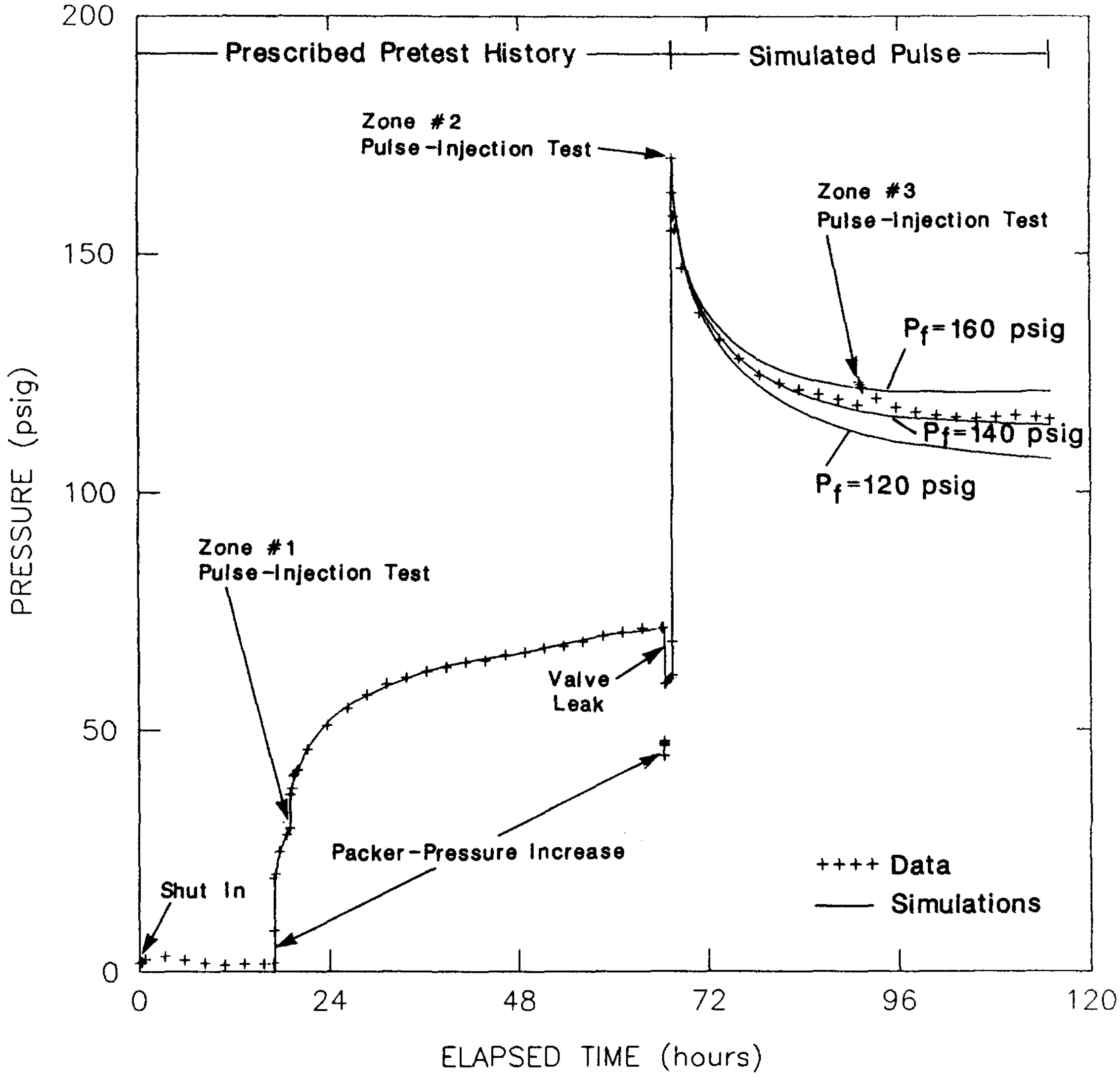
| INTERA Technologies | | Figure 5.5 |

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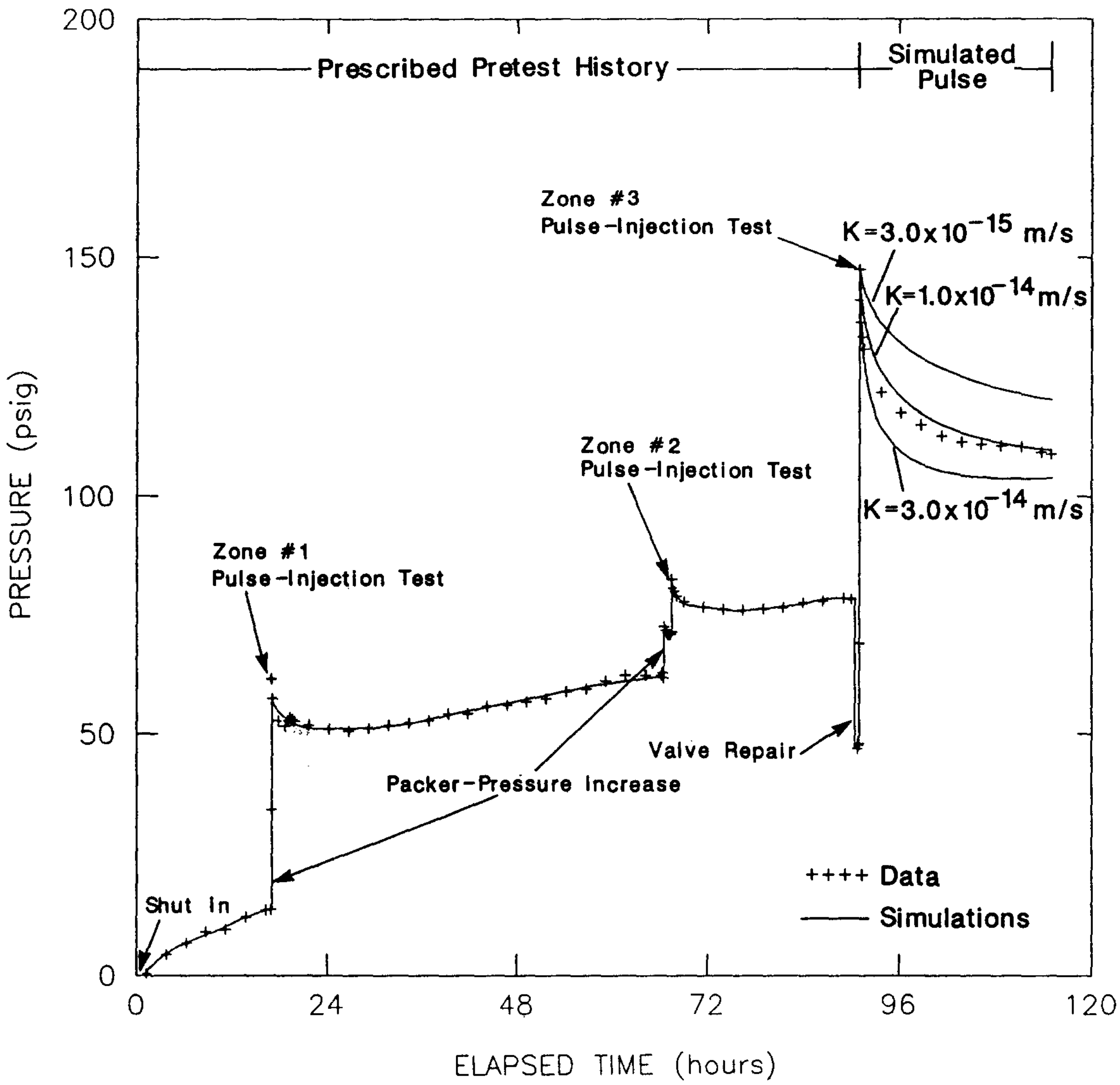
INTERA Technologies

Simulation of the Borehole W782W Zone #2 Pulse-Injection Test; Hydraulic Conductivity = $1.0 \times 10^{-14}$ m/s and Varying Formation Pressure

Figure 5.6

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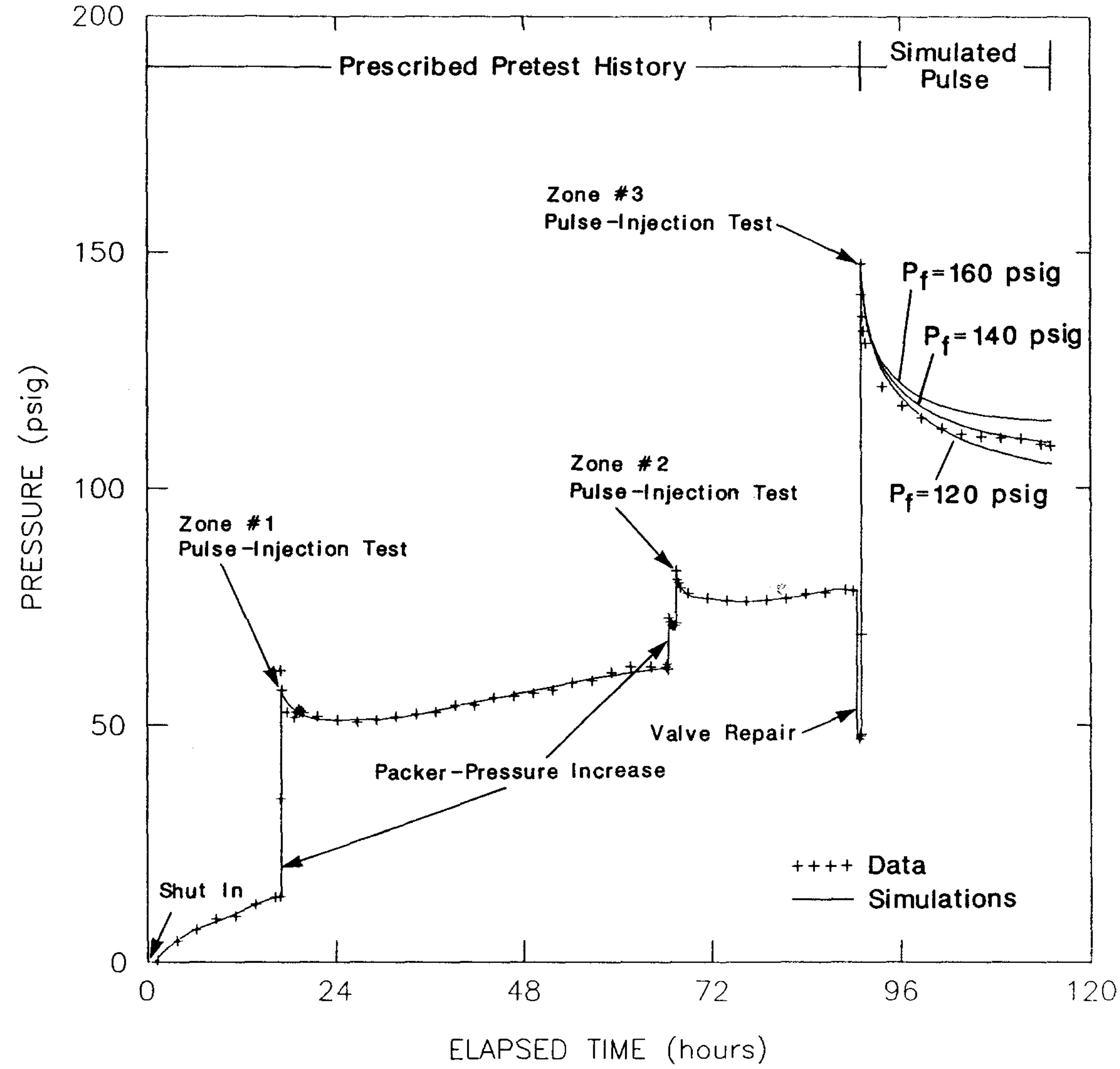
| INTERA Technologies | | Figure 5.7 |

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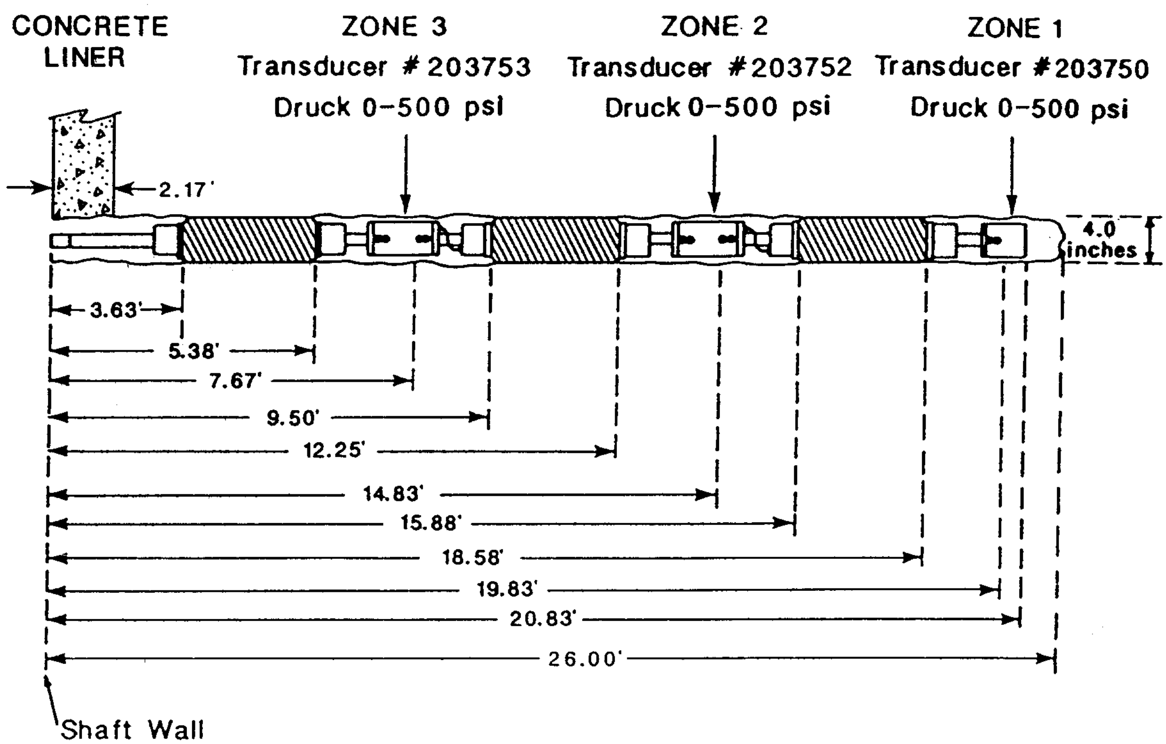
INTERA Technologies

Simulation of the Borehole W782W Zone #3 Pulse-Injection Test; Hydraulic Conductivity = 1.0 x $10^{-14}$ m/s and Varying Formation Pressure

Figure 5.8

SHAFT LEVEL: 805 feet BGS

BOREHOLE LOCATION: W805E (East Wall)

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| Drawn by | Date | Configuration of the Multipacker Test Tool in Borehole W805E |
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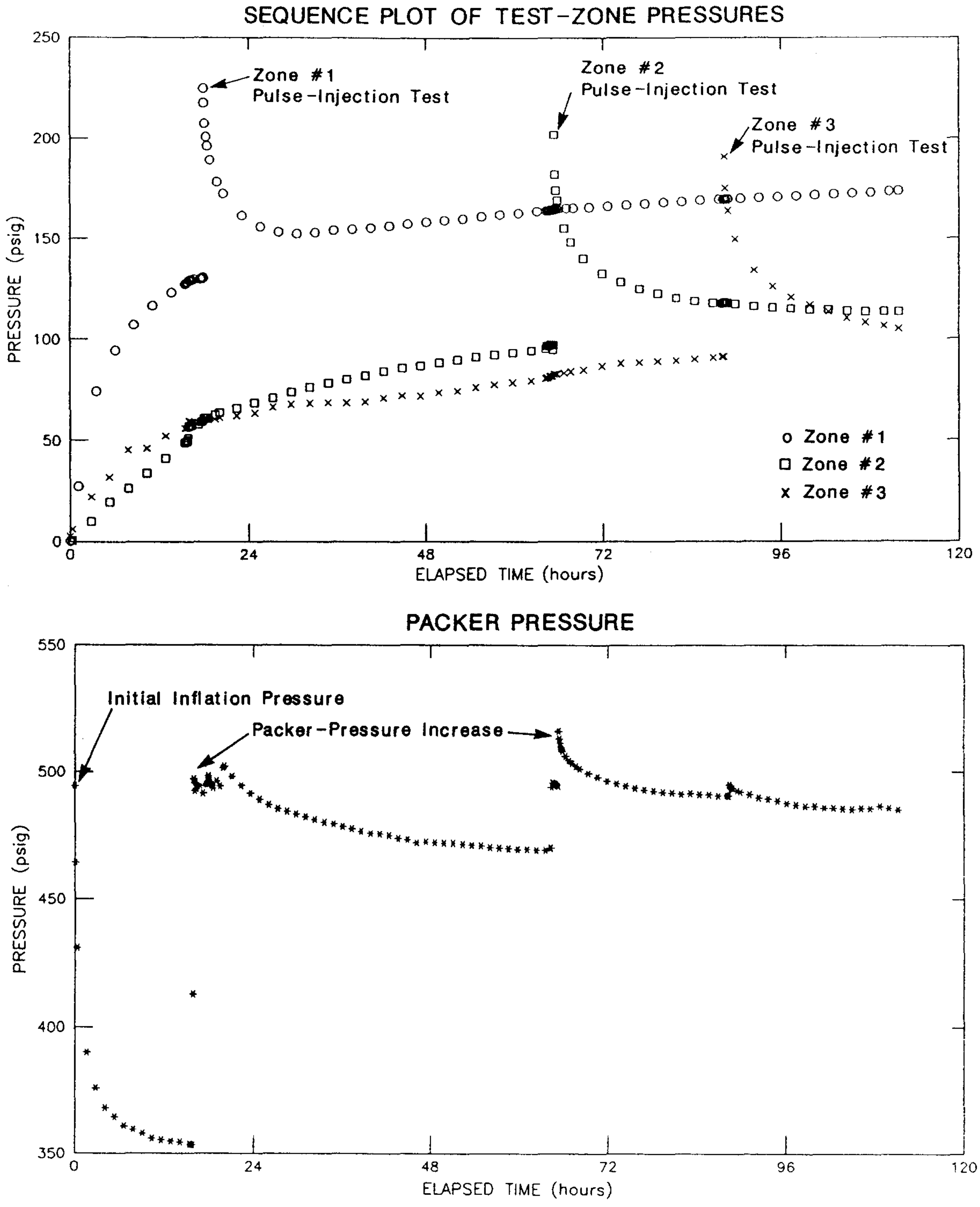
| INTERA Technologies | | Figure 5.9 |




| Drawn by | Date | Linear-Linear Sequence Plot of the Test-Zone and Packer-Inflation Pressures During Testing in Borehole W805E |
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| Revisions | Date | |
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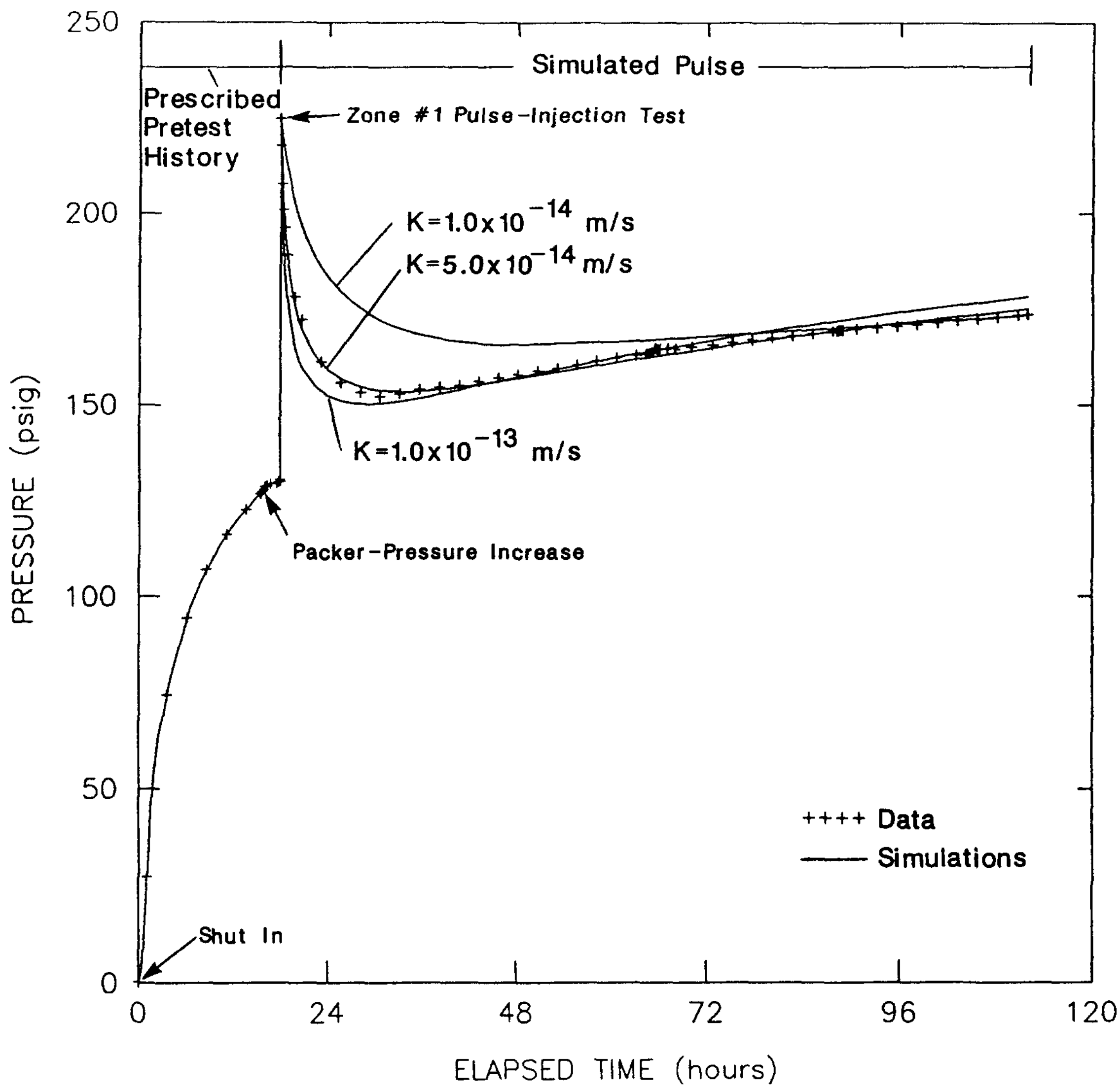
INTERA Technologies

Figure 5.10

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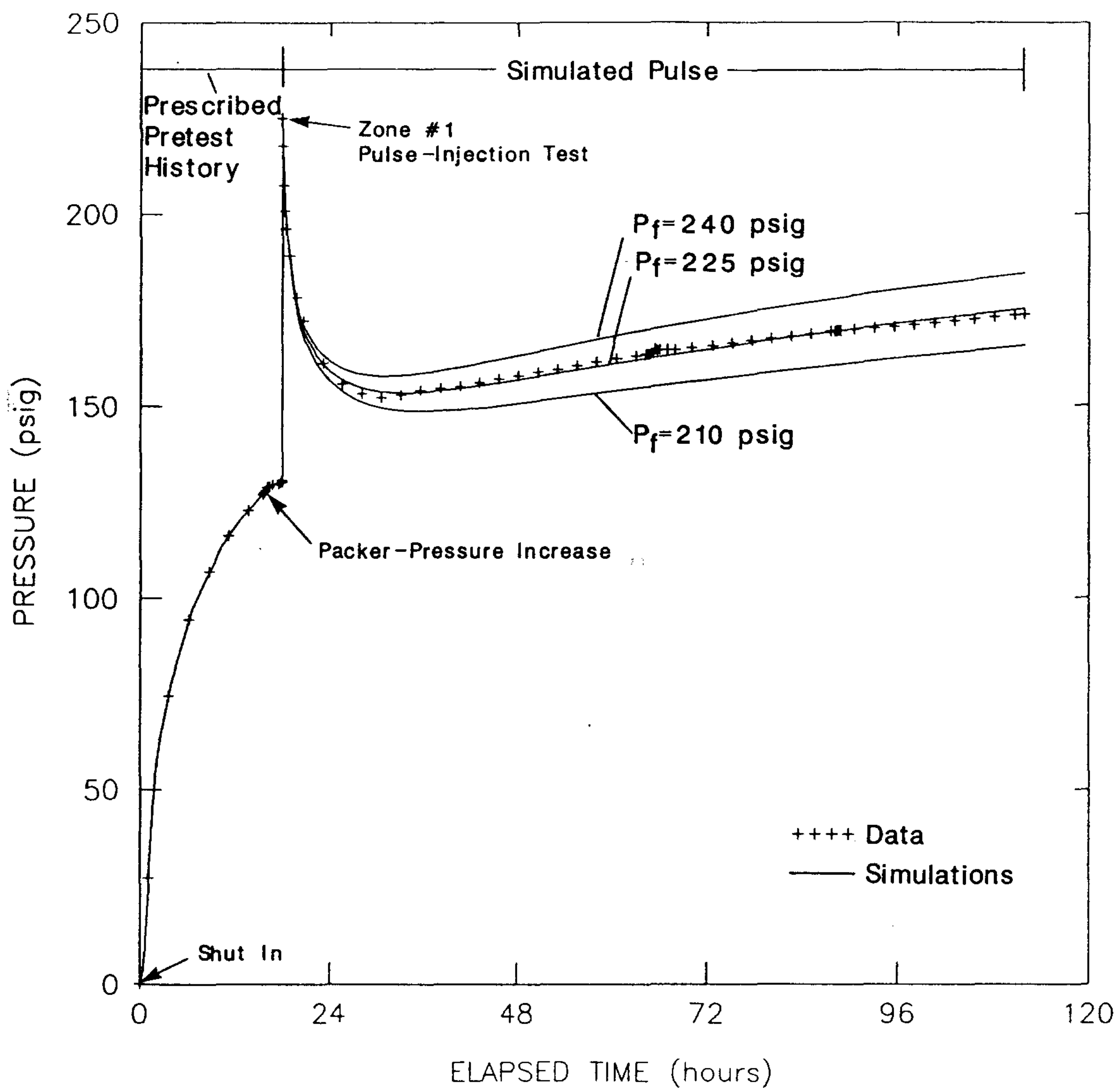
Simulation of the Borehole W805E Zone #1 Pulse-Injection Test; Formation Pressure = 225 psig and Varying Hydraulic Conductivity

INTERA Technologies

Figure 5.11

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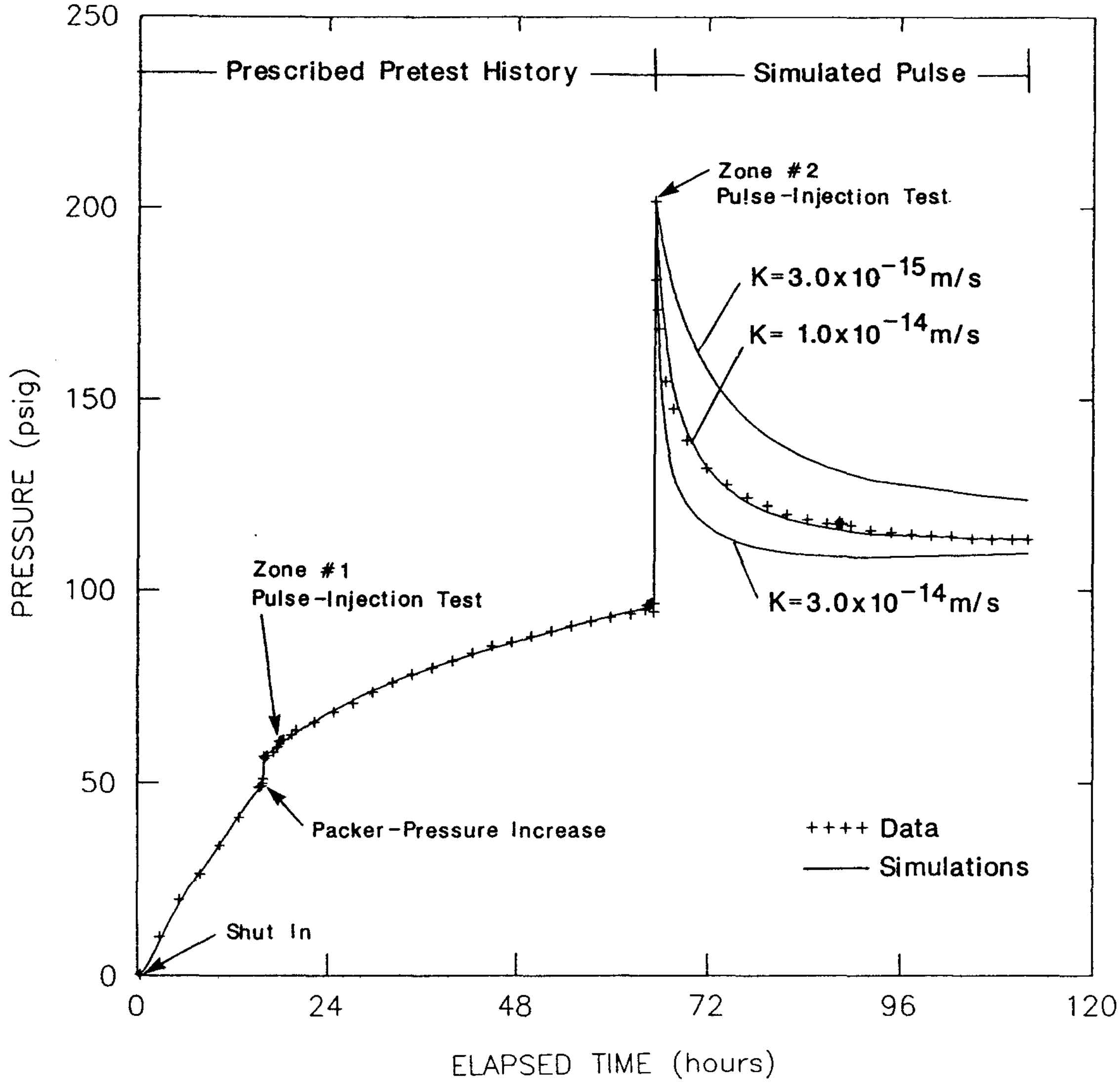
Simulation of the Borehole W805E Zone #1 Pulse-Injection Test; Hydraulic Conductivity = 5.0 x $10^{-14}$ m/s and Varying Formation Pressure

INTERA Technologies

Figure 5.12




| Drawn by | Date | Simulation of the Borehole W805E Zone #2 Pulse-Injection Test; Formation Pressure = 140 psig and Varying Hydraulic Conductivity |
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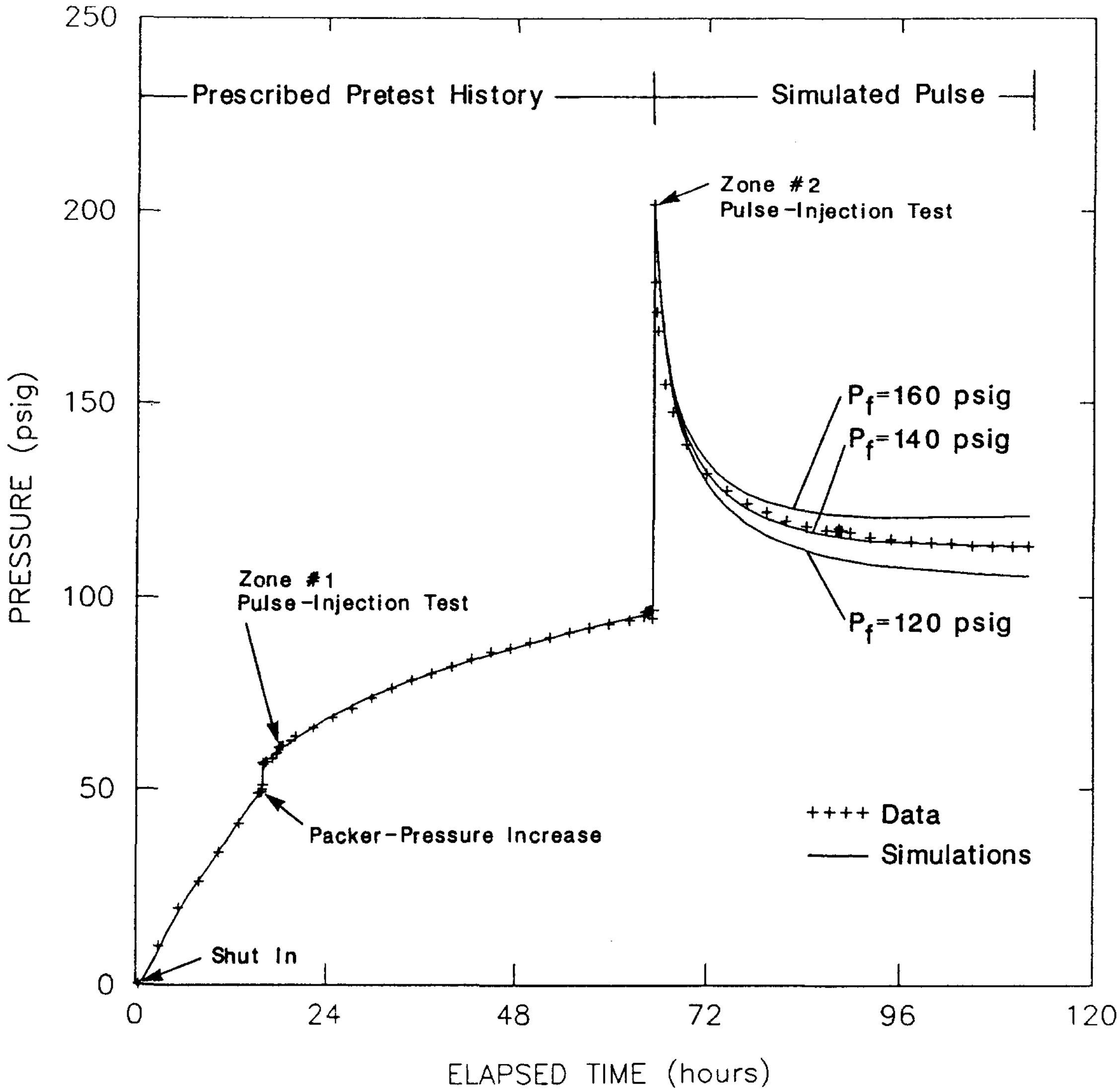
INTERA Technologies

Figure 5.13

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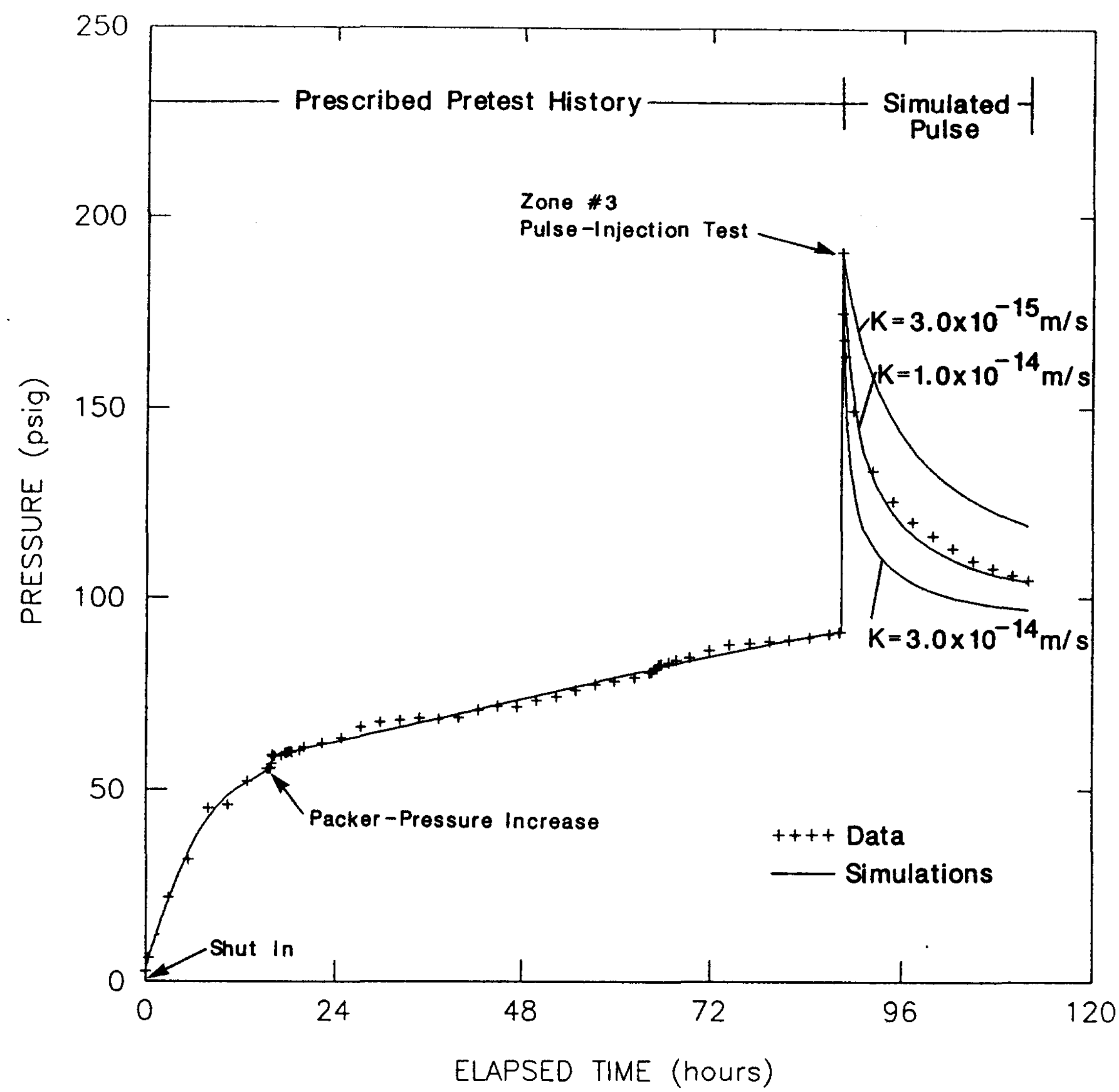
| INTERA Technologies | | Figure 5.14 |

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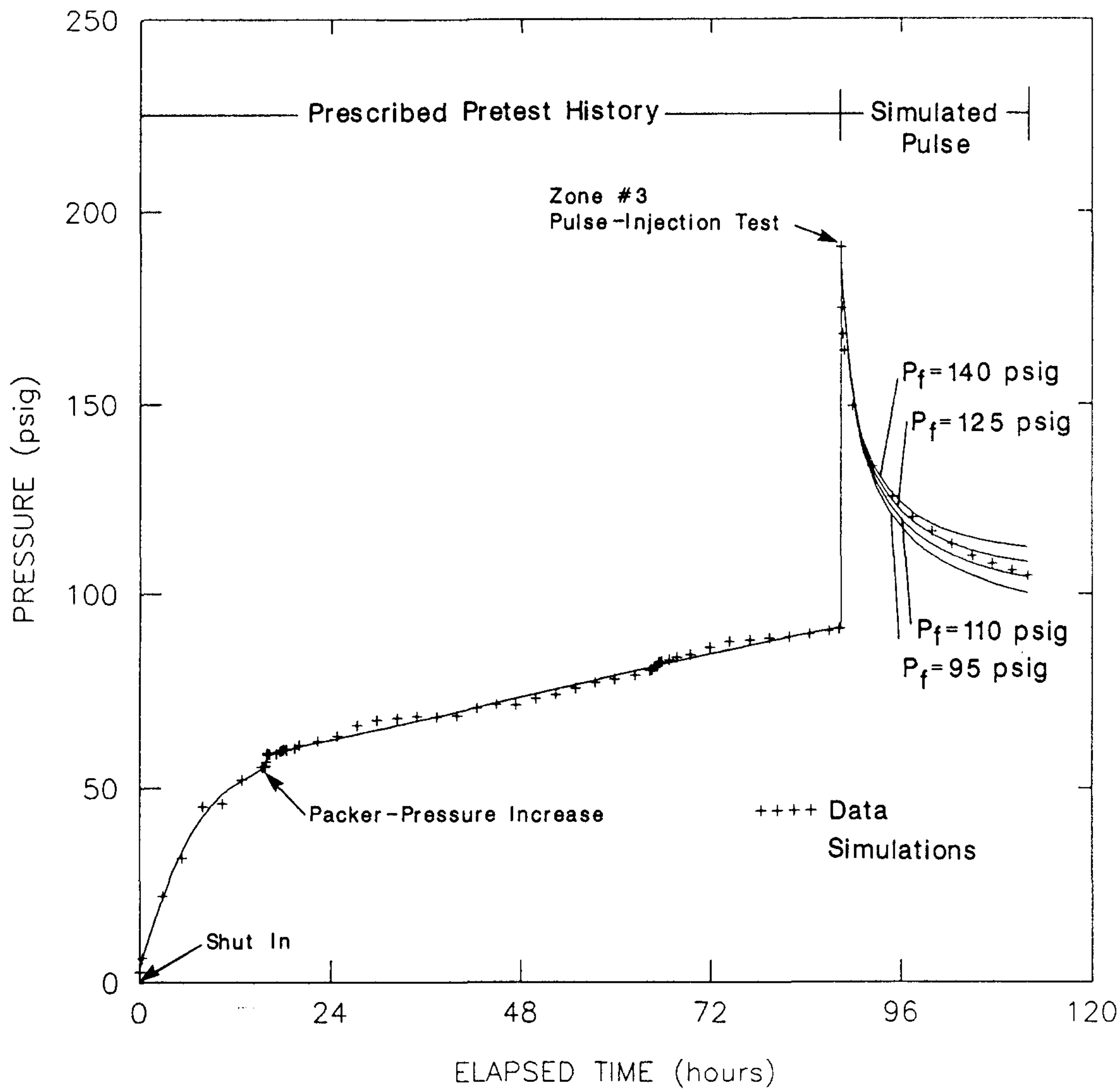
| INTERA Technologies | | Figure 5.15 |




| Drawn by | Date | Simulation of the Borehole W805E Zone #3 Pulse-Injection Test; Hydraulic Conductivity = 1.0 x $10^{-14}$ m/s and Varying Formation Pressure |
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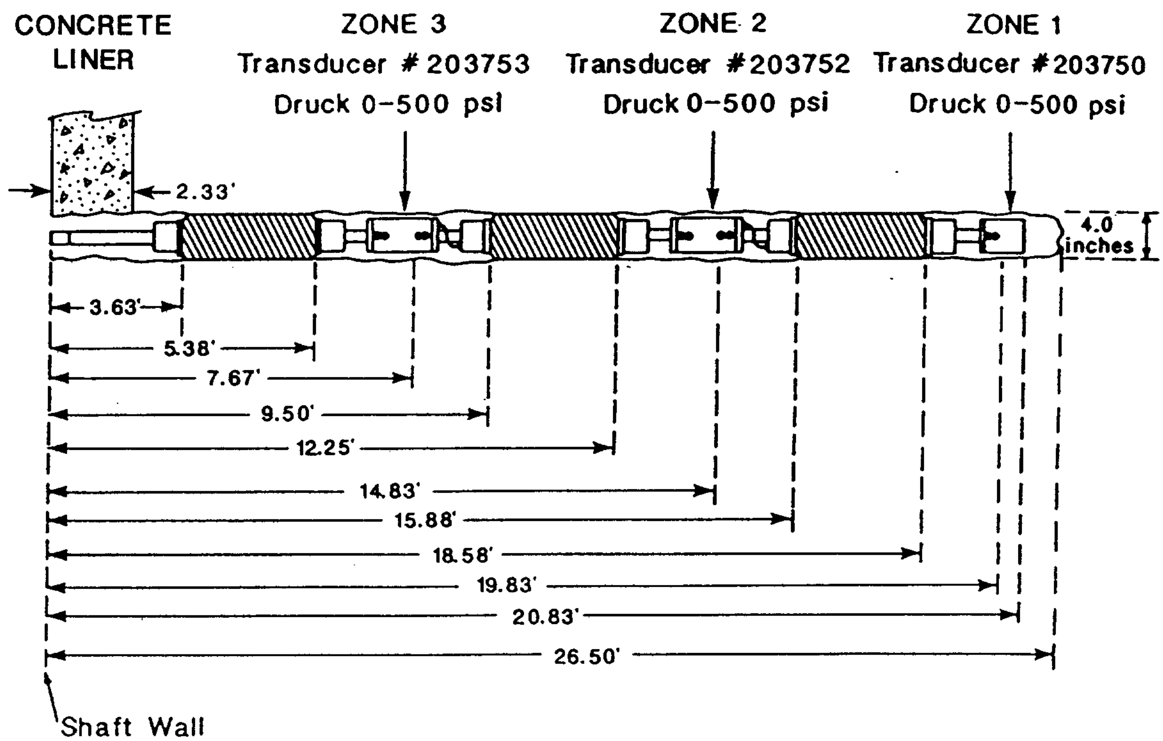
| INTERA Technologies | | Figure 5.16 |

SHAFT LEVEL: 805 feet BGS

BOREHOLE LOCATION: W805SW (Southwest Wall)




| Drawn by | Date | Configuration of the Multipacker Test Tool in Borehole W805SW |
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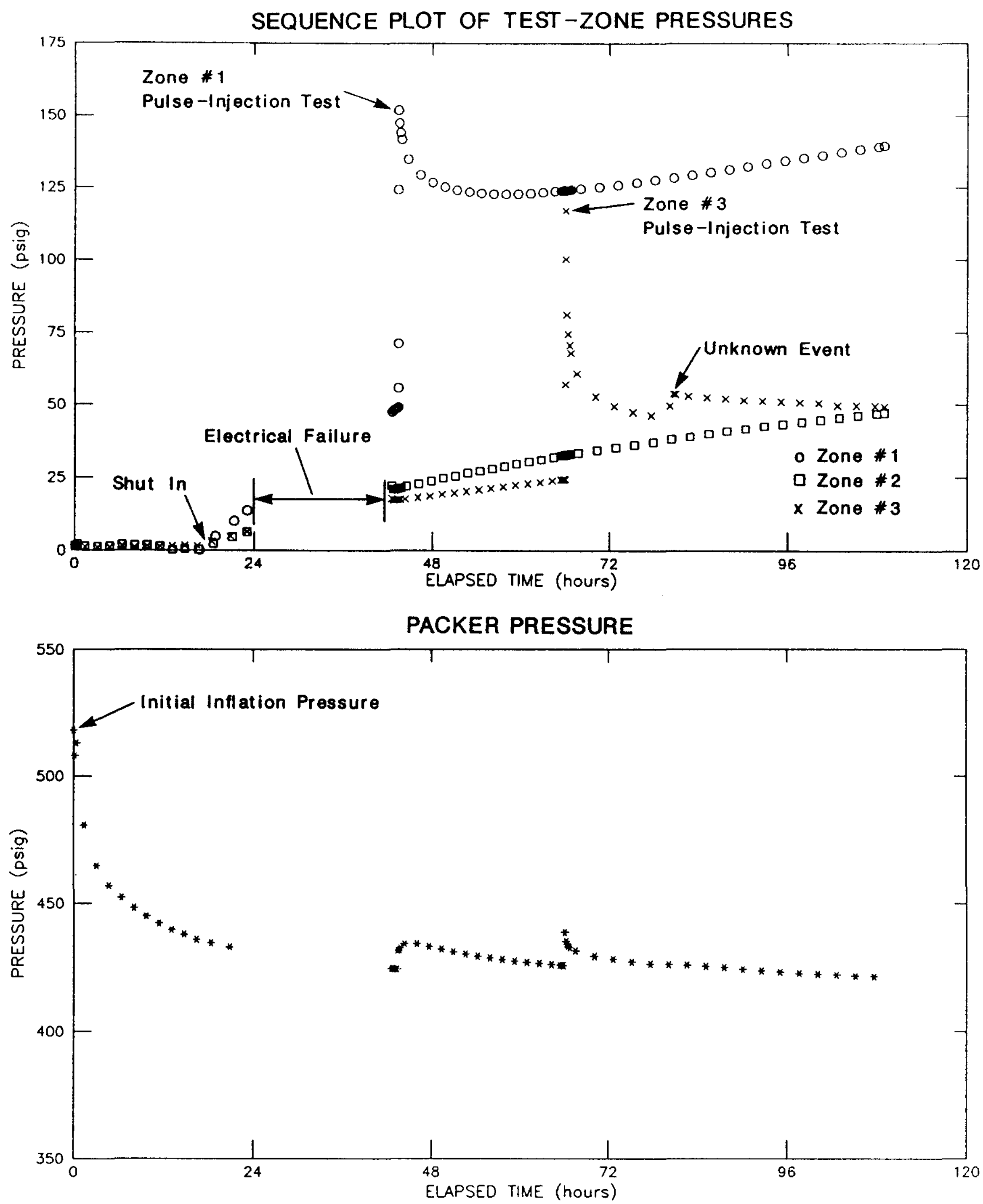
| INTERA Technologies | | Figure 5.17 |




| Drawn by | Date | Linear-Linear Sequence Plot of the Test-Zone and Packer-Inflation Pressures During Testing in Borehole W805SW |
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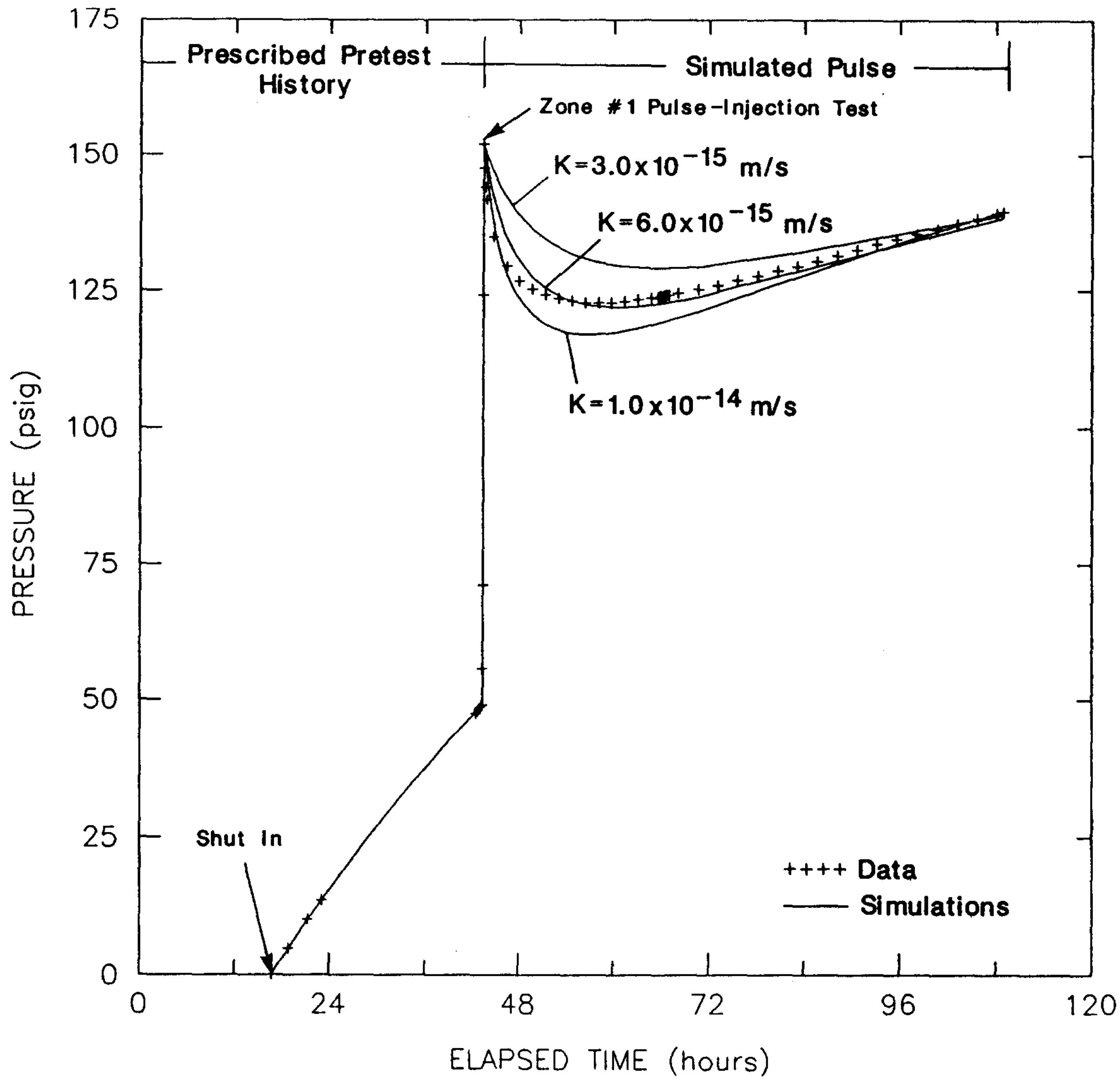
| INTERA Technologies | | Figure 5.18 |

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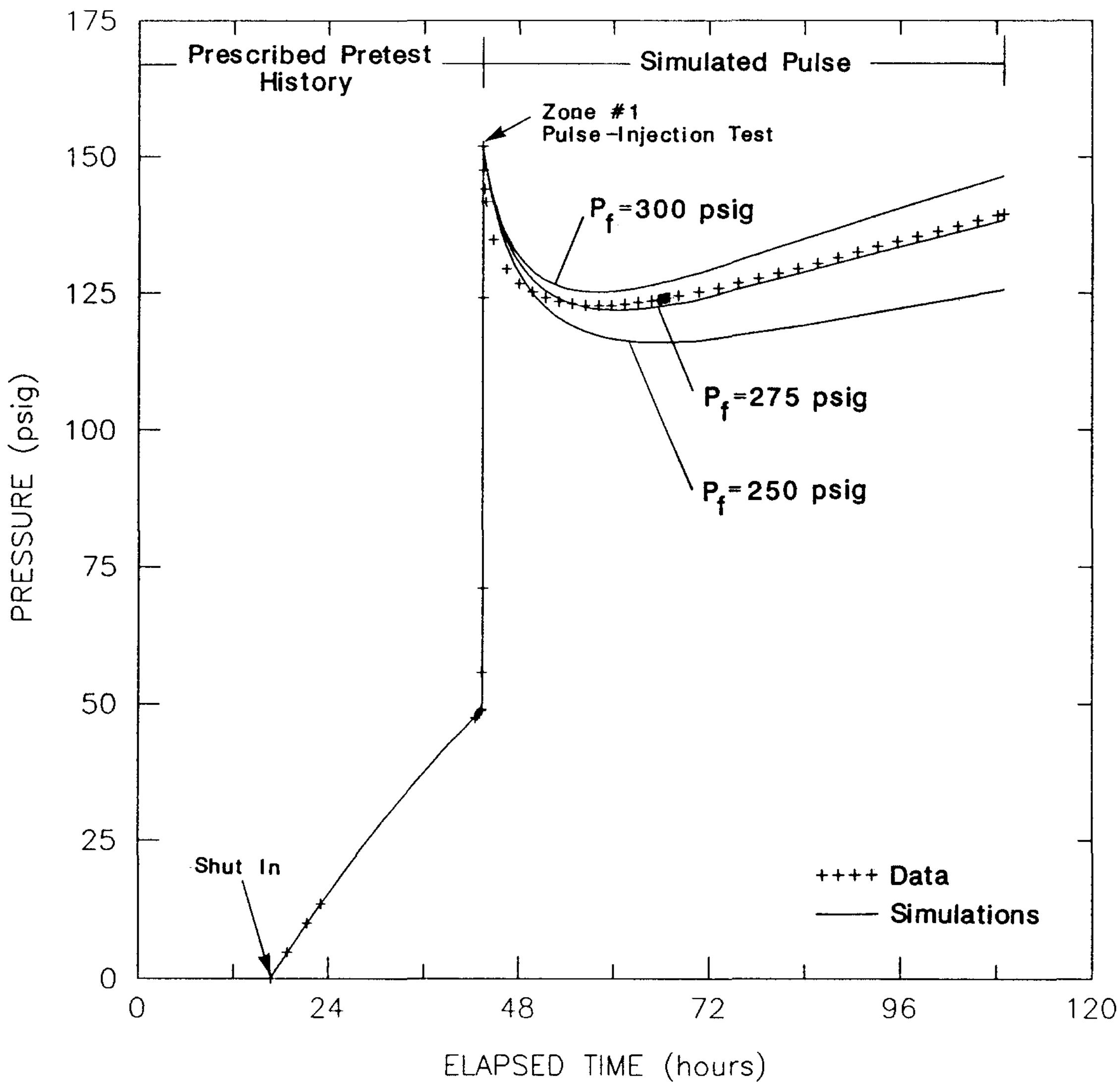
Simulation of the Borehole W805SW Zone #1 Pulse-Injection Test; Formation Pressure = 275 psig and Varying Hydraulic Conductivity

INTERA Technologies

Figure 5.19

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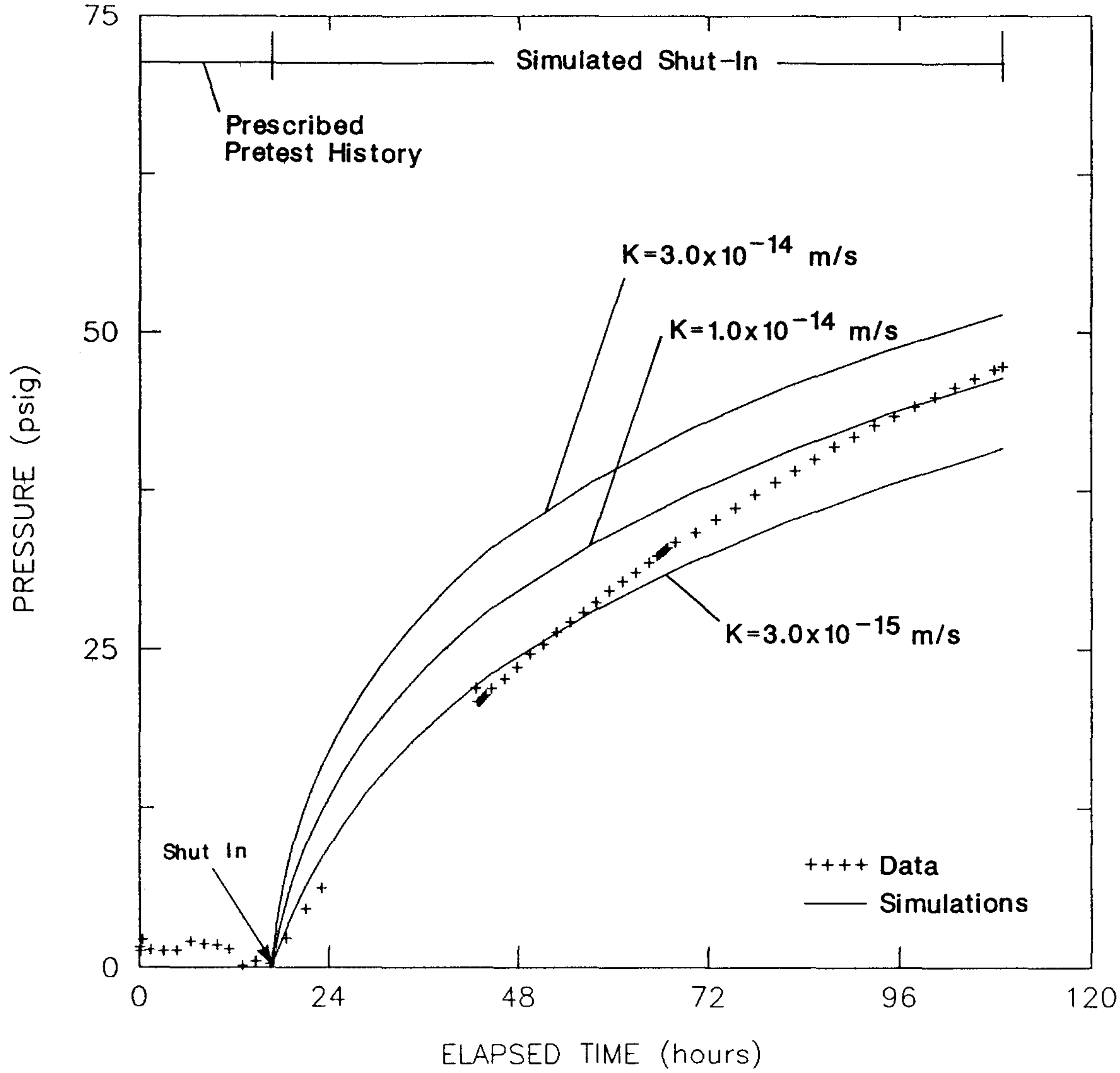
Simulation of the Borehole W805SW Zone #1 Pulse-Injection Test; Hydraulic Conductivity = $6.0 \times 10^{-15}$ m/s and Varying Formation Pressure

INTERA Technologies

Figure 5.20

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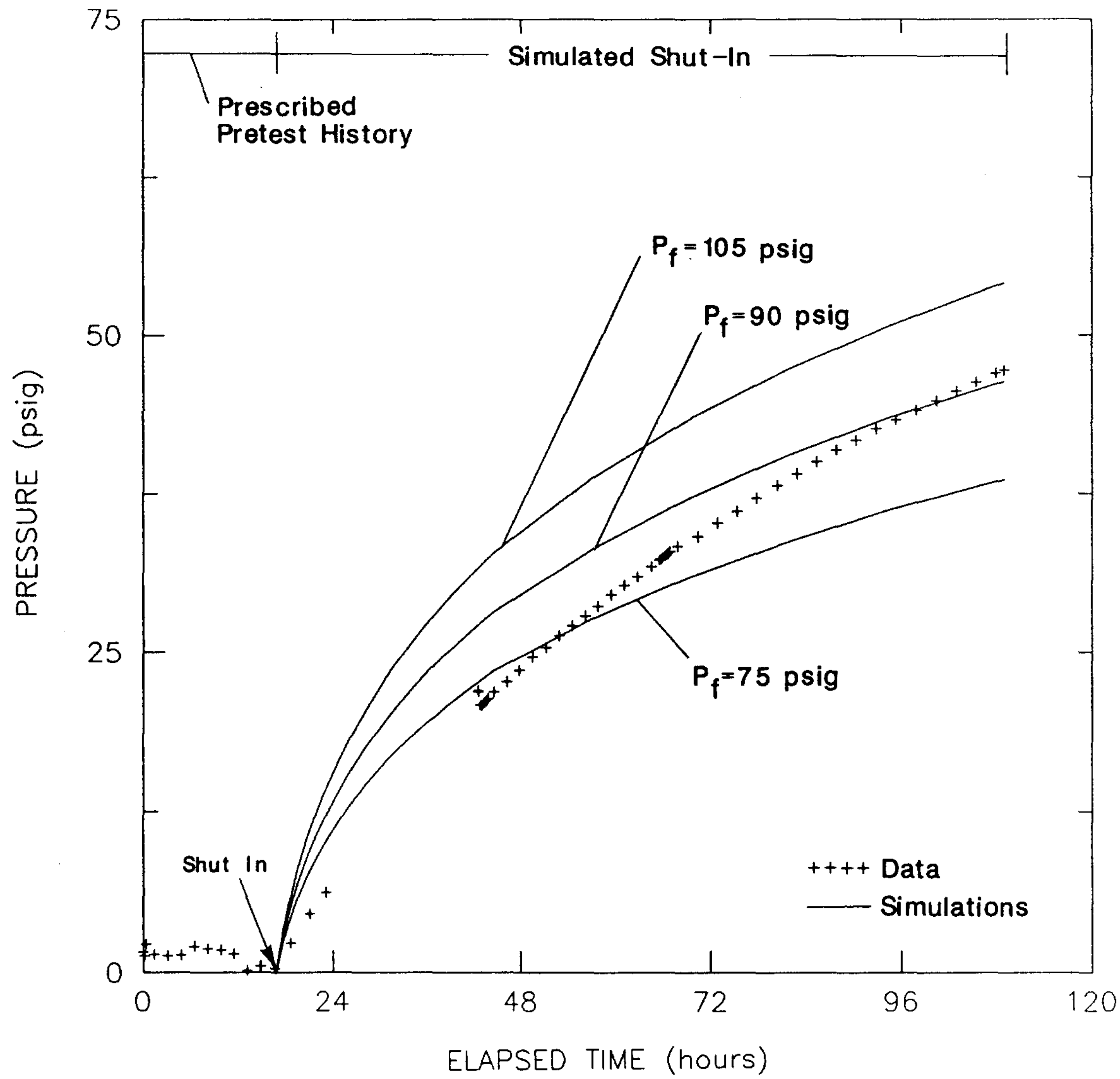
| INTERA Technologies | | Figure 5.21 |




| Drawn by | Date | Simulation of the Borehole W805SW Zone #2 Shut-In Test; Hydraulic Conductivity = 1.0 x $10^{-14}$ m/s and Varying Formation Pressure |
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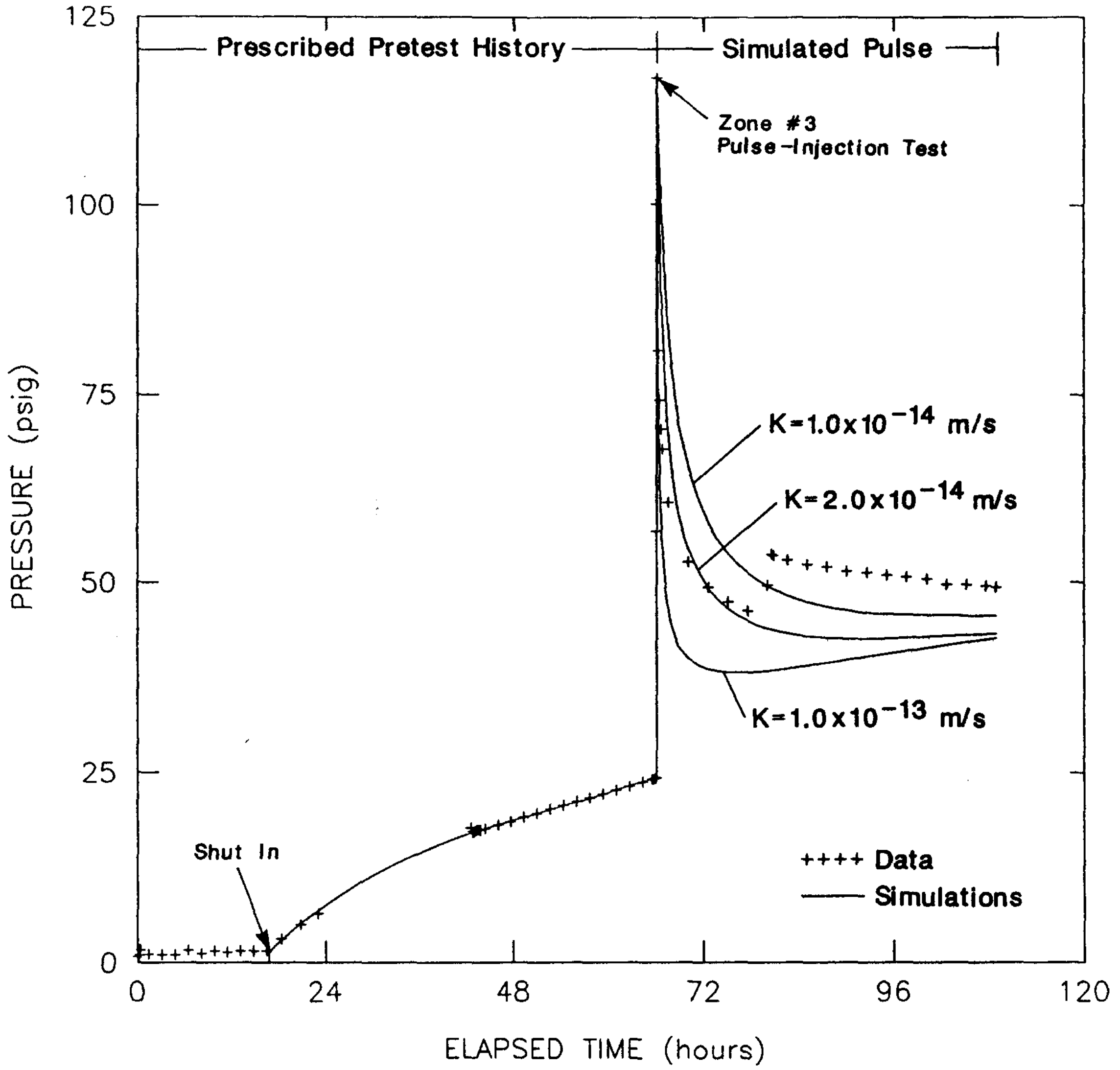
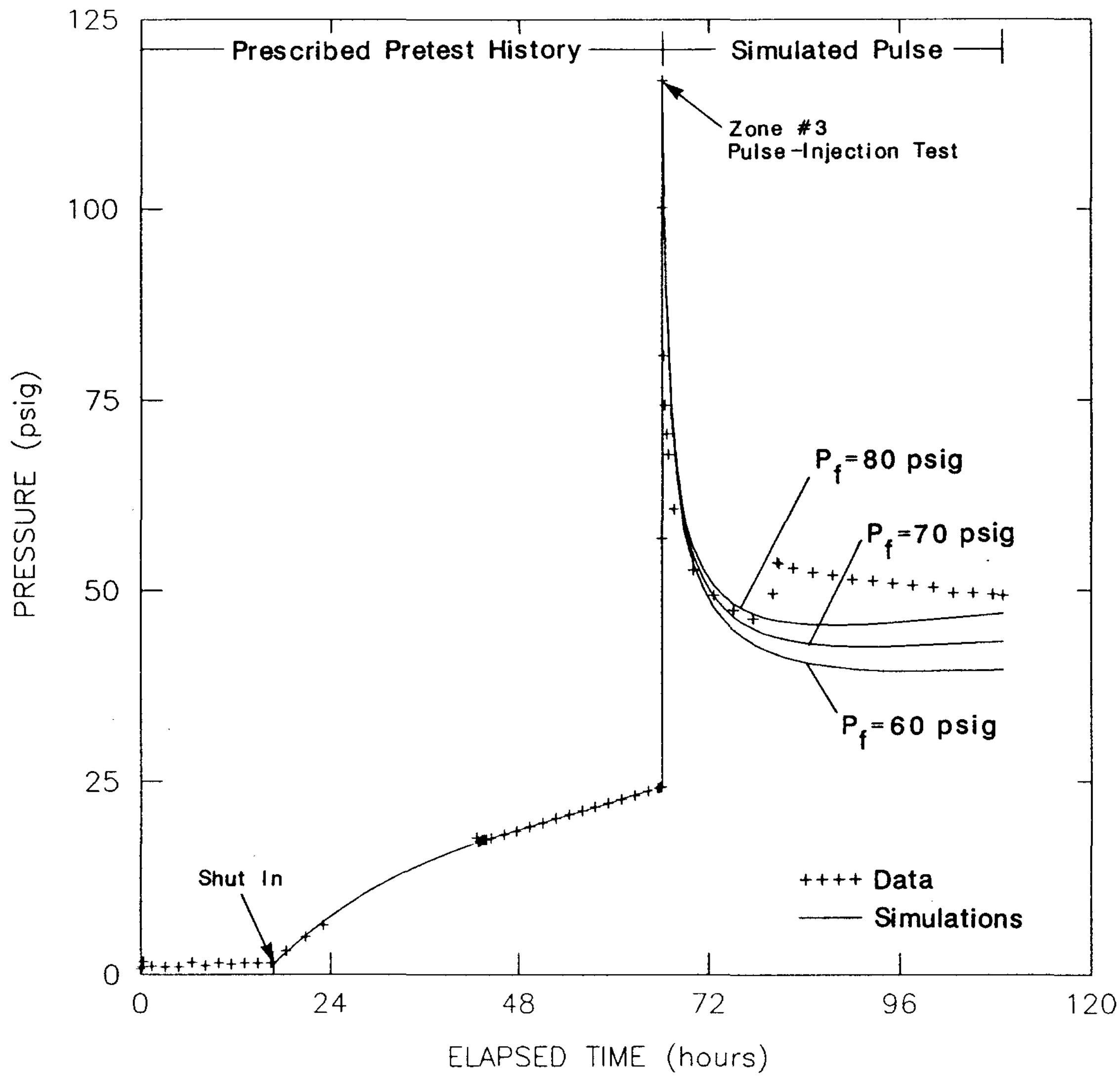
| H09700R570 | | |
| INTERA Technologies | | Figure 5.22 |




| Drawn by | Date | Simulation of the Borehole W805SW Zone #3 Pulse-Injection Test; Formation Pressure = 70 psig and Varying Hydraulic Conductivity |
|---|---|---|
| Checked by | Date | |
| Revisions | Date | |
| H09700R570 | | |
| INTERA Technologies | | Figure 5.23 |




| | |
|---|---|
| Drawn by | Date |
| Checked by | Date |
| Revisions | Date |
| H09700R570 | |

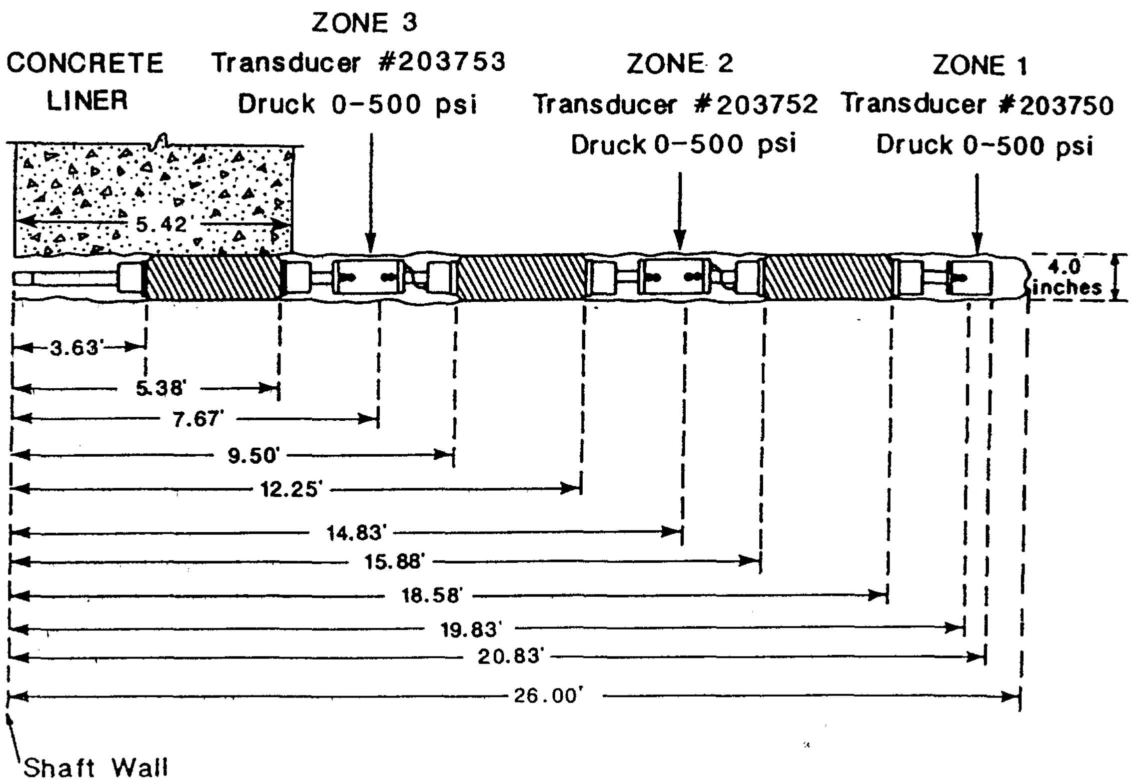
Simulation of the Borehole W805SW Zone #3 Pulse-Injection Test; Hydraulic Conductivity = $2.0 \times 10^{-14}$ m/s and Varying Formation Pressure

INTERA Technologies

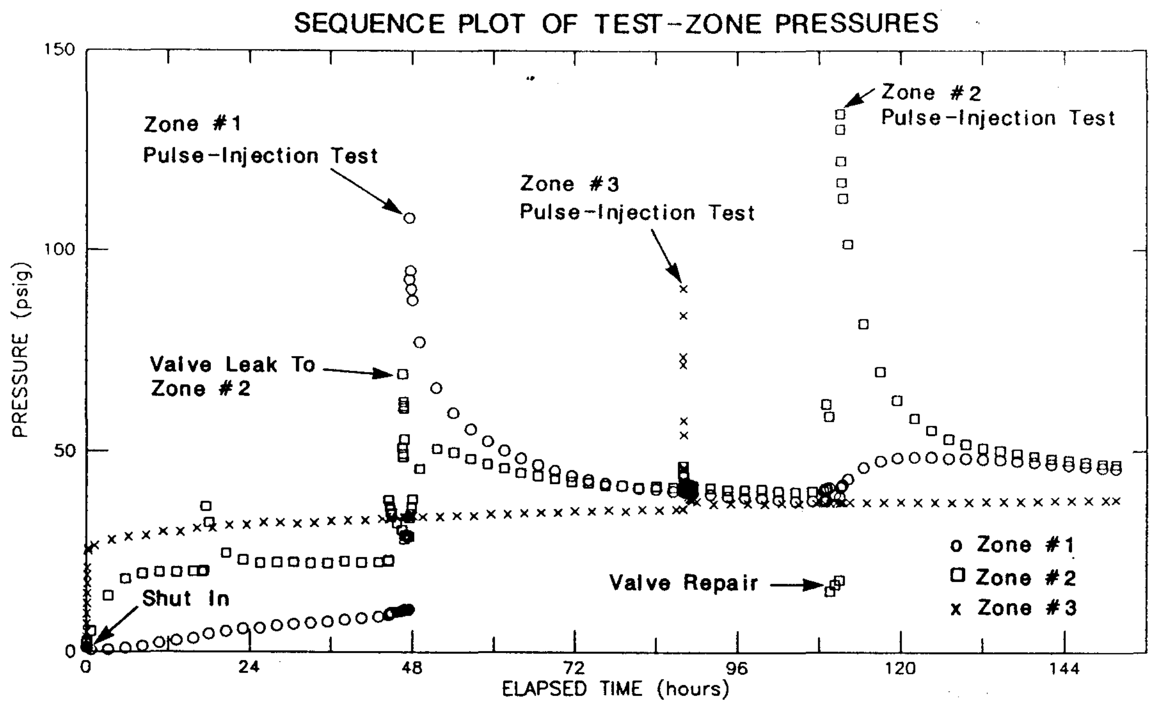
Figure 5.24

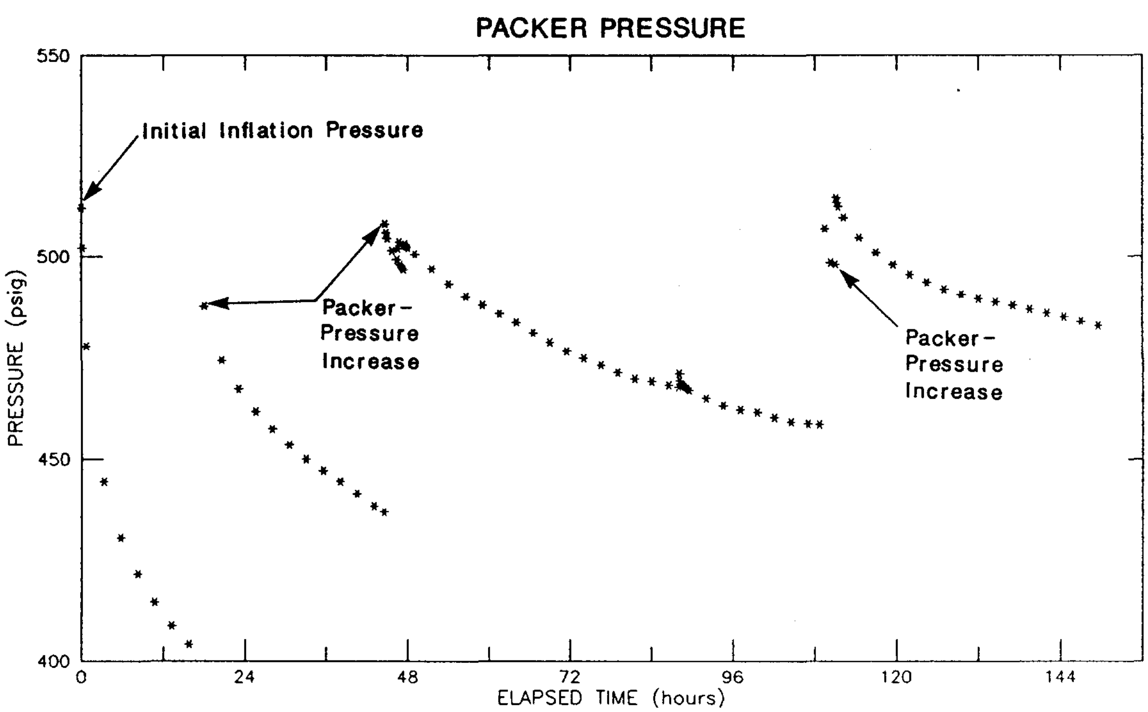
SHAFT LEVEL: 850 feet BGS

BOREHOLE LOCATION: W850W (West Wall)




| | | |
|---|---|---|
| Drawn by | Date | Configuration of the Multipacker Test Tool in Borehole W850W |
| Checked by | Date | |
| Revisions | Date | |
| H09700R570 | | |
| INTERA Technologies | | Figure 5.25 |



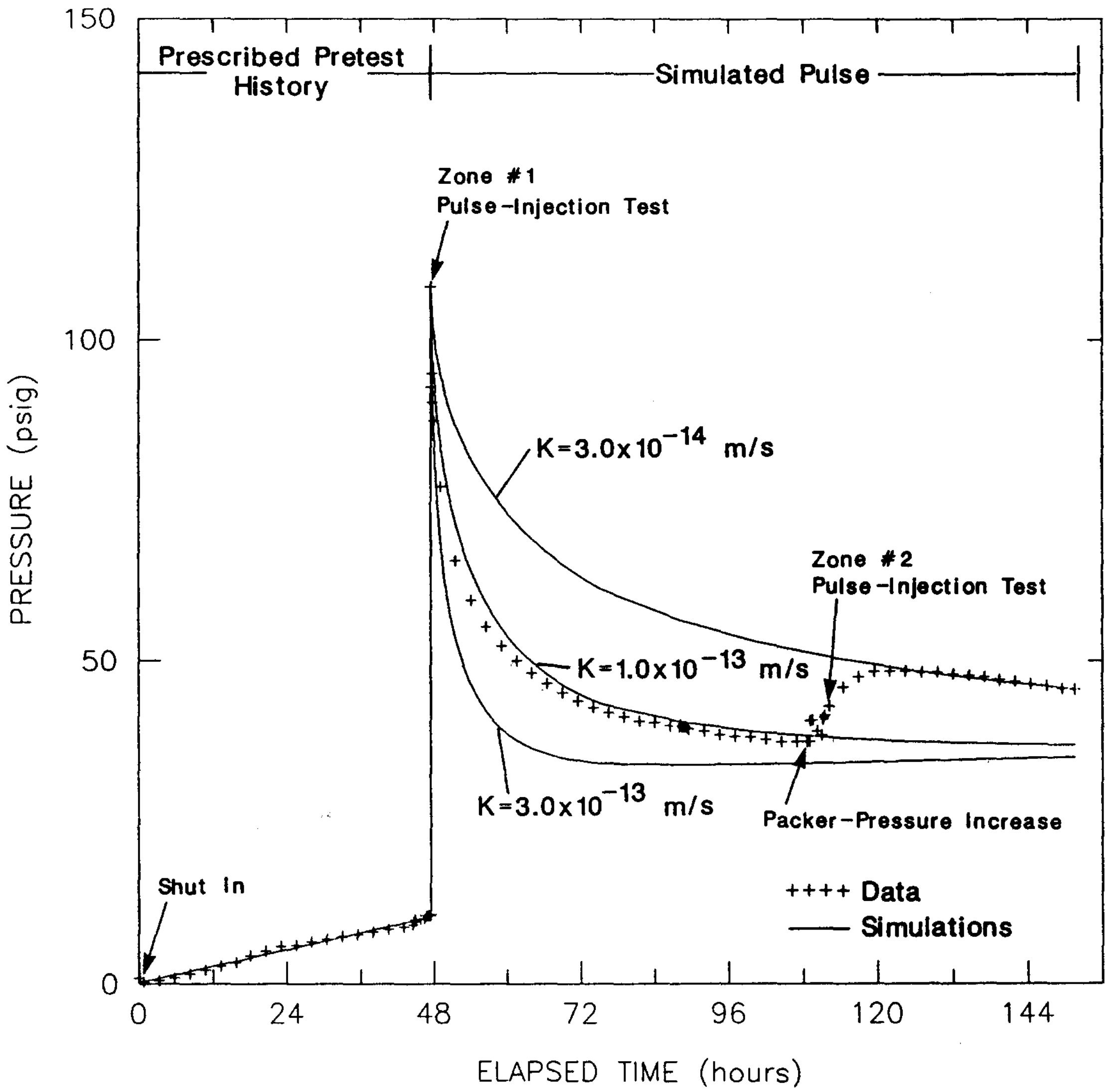




| Drawn by | Date |
|---|---|
| Checked by | Date |
| Revisions | Date |
| H09700R570 | |

INTERA Technologies

Linear-Linear Sequence Plot of the Test-Zone and Packer-Inflation Pressures During Testing in Borehole W850W

Figure 5.26




| Drawn by | Date |
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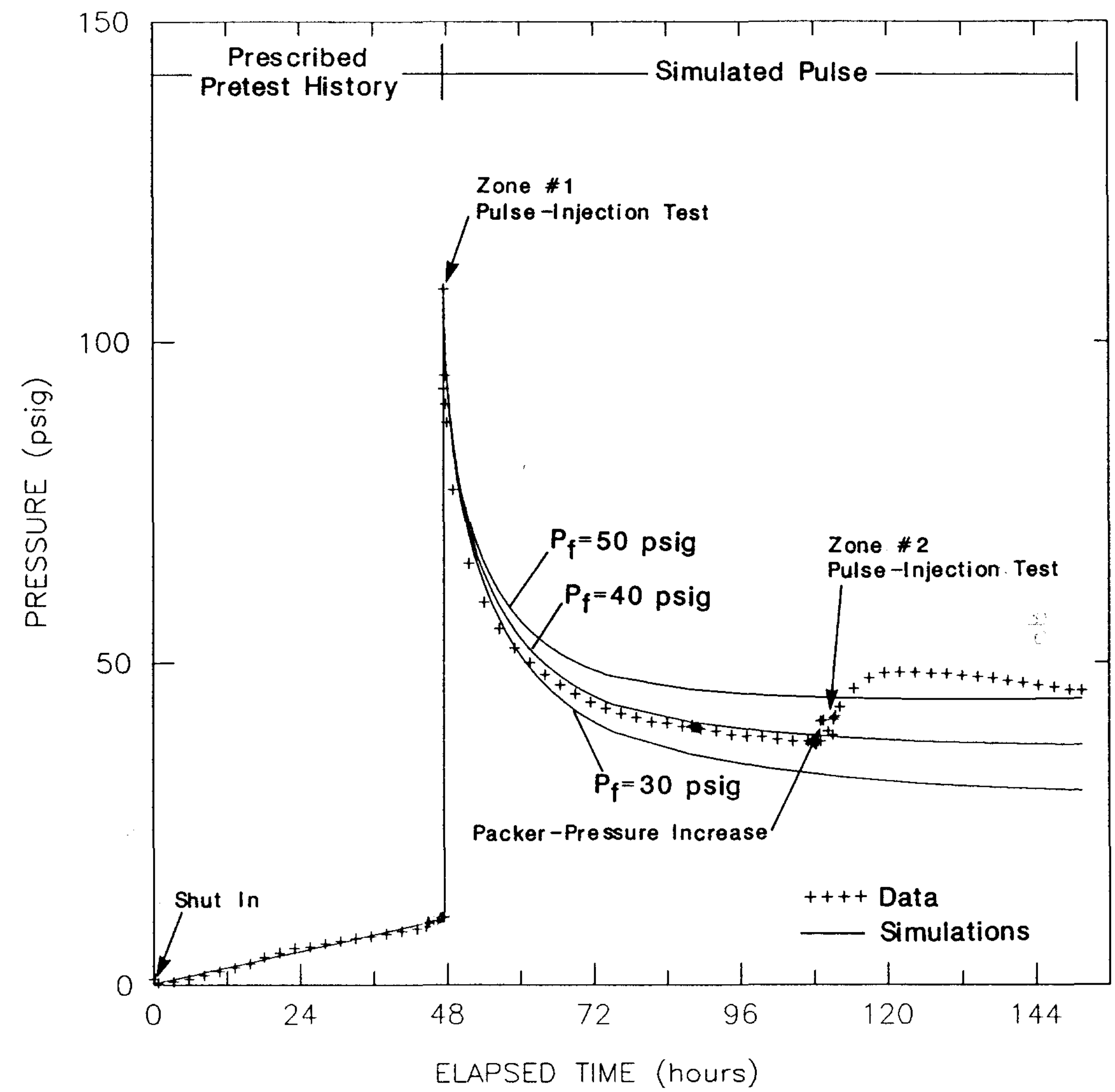
| Checked by | Date |
| Revisions | Date |
| H09700R570 | |

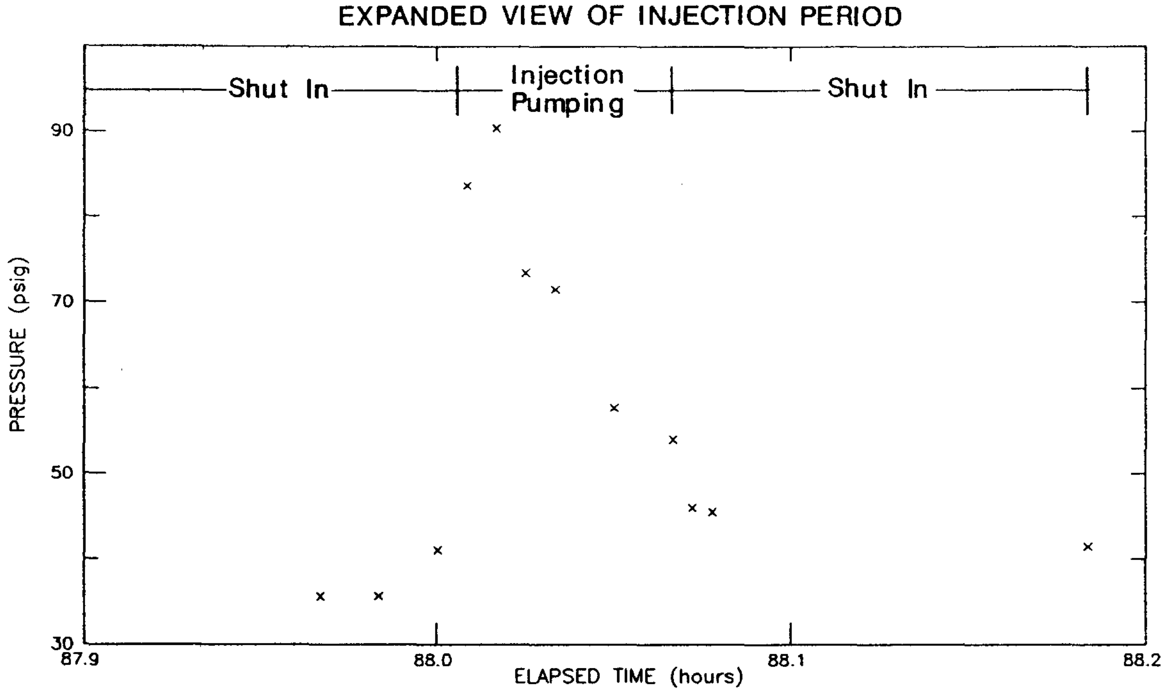
Simulation of the Borehole W850W Zone #1 Pulse-Injection Test; Formation Pressure = 40 psig and Varying Hydraulic Conductivity

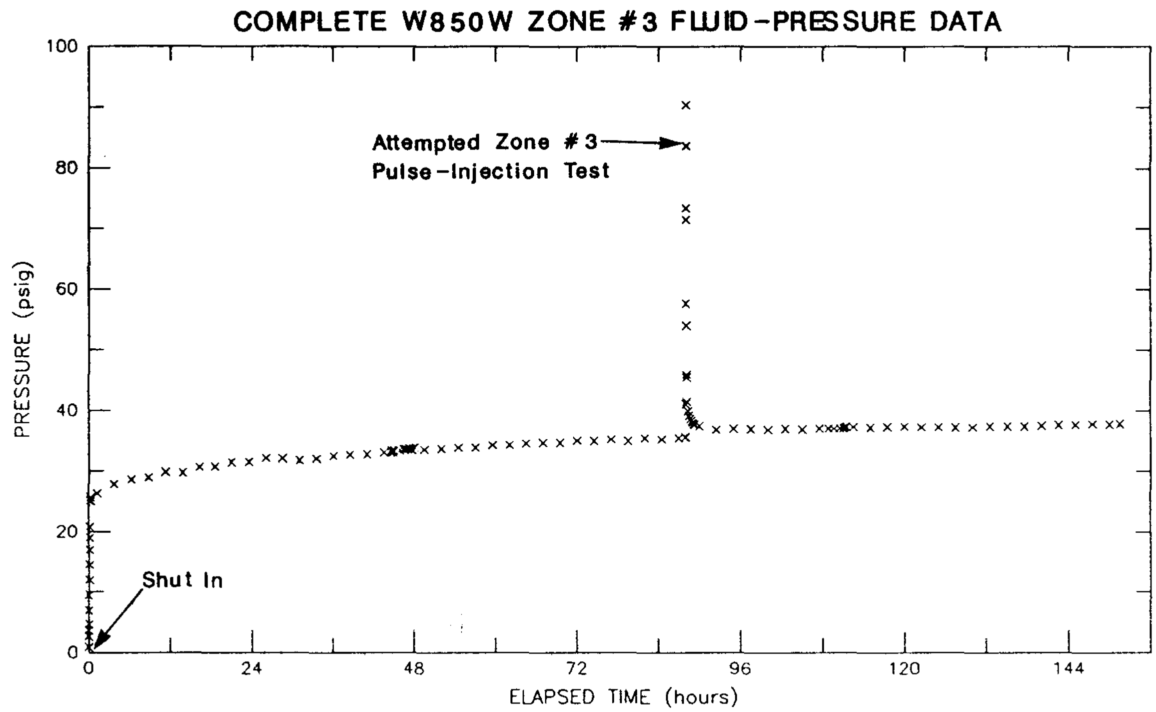
INTERA Technologies

Figure 5.27

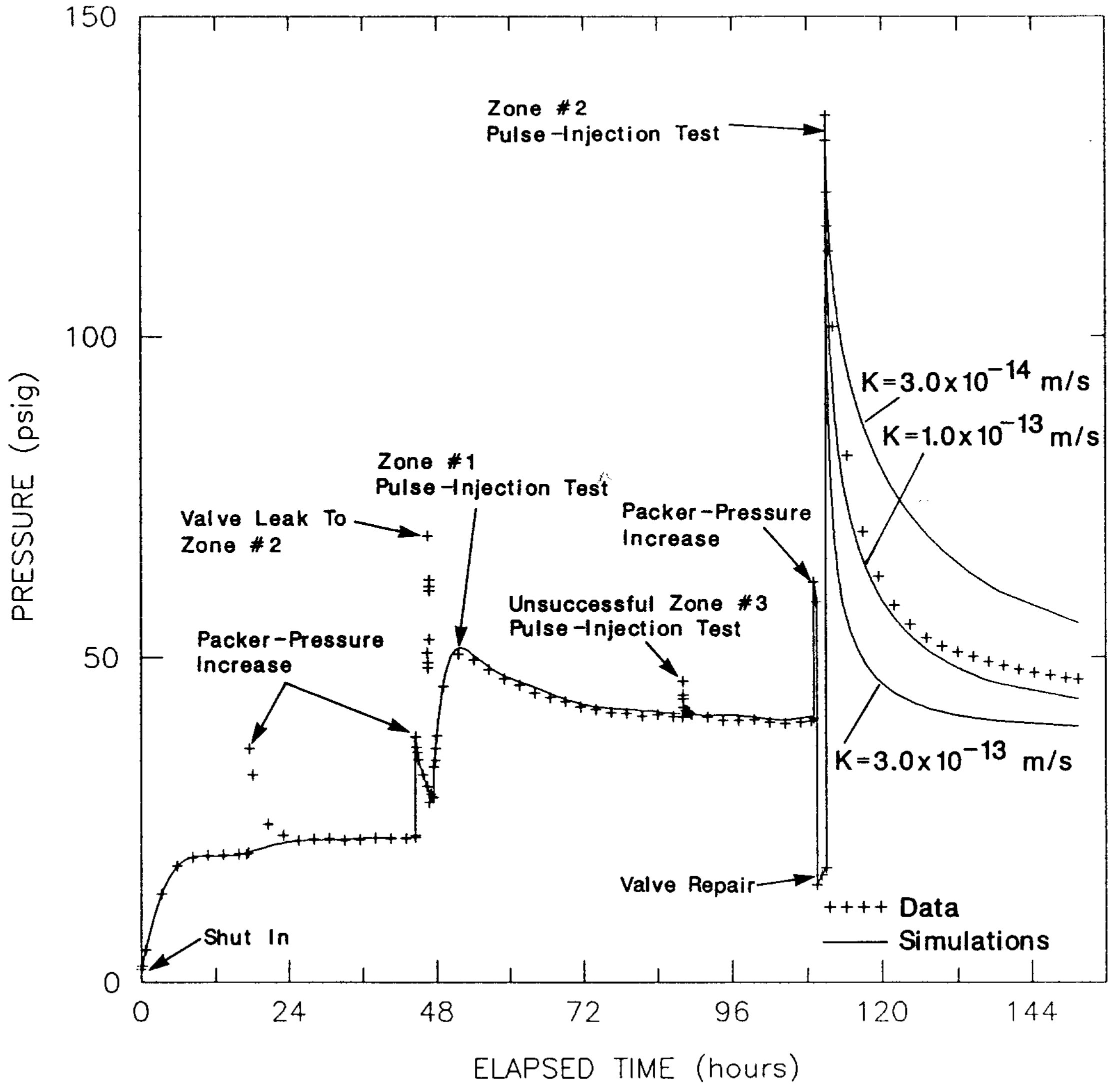



| | | |
|---|---|---|
| Drawn by | Date | Simulation of the Borehole W850W Zone #1 Pulse-Injection Test; Hydraulic Conductivity = 1.0 x $10^{-13}$ m/s and Varying Formation Pressure |
| Checked by | Date | |
| Revisions | Date | |
| H09700R570 | | |
| INTERA Technologies | | Figure 5.28 |




| Drawn by | Date | Unsuccessful Pulse-Injection in Zone #3, Borehole W850W |
|---|---|---|
| Checked by | Date | |
| Revisions | Date | |
| H09700R570 | | |
| INTERA Technologies | | Figure 5.29 |

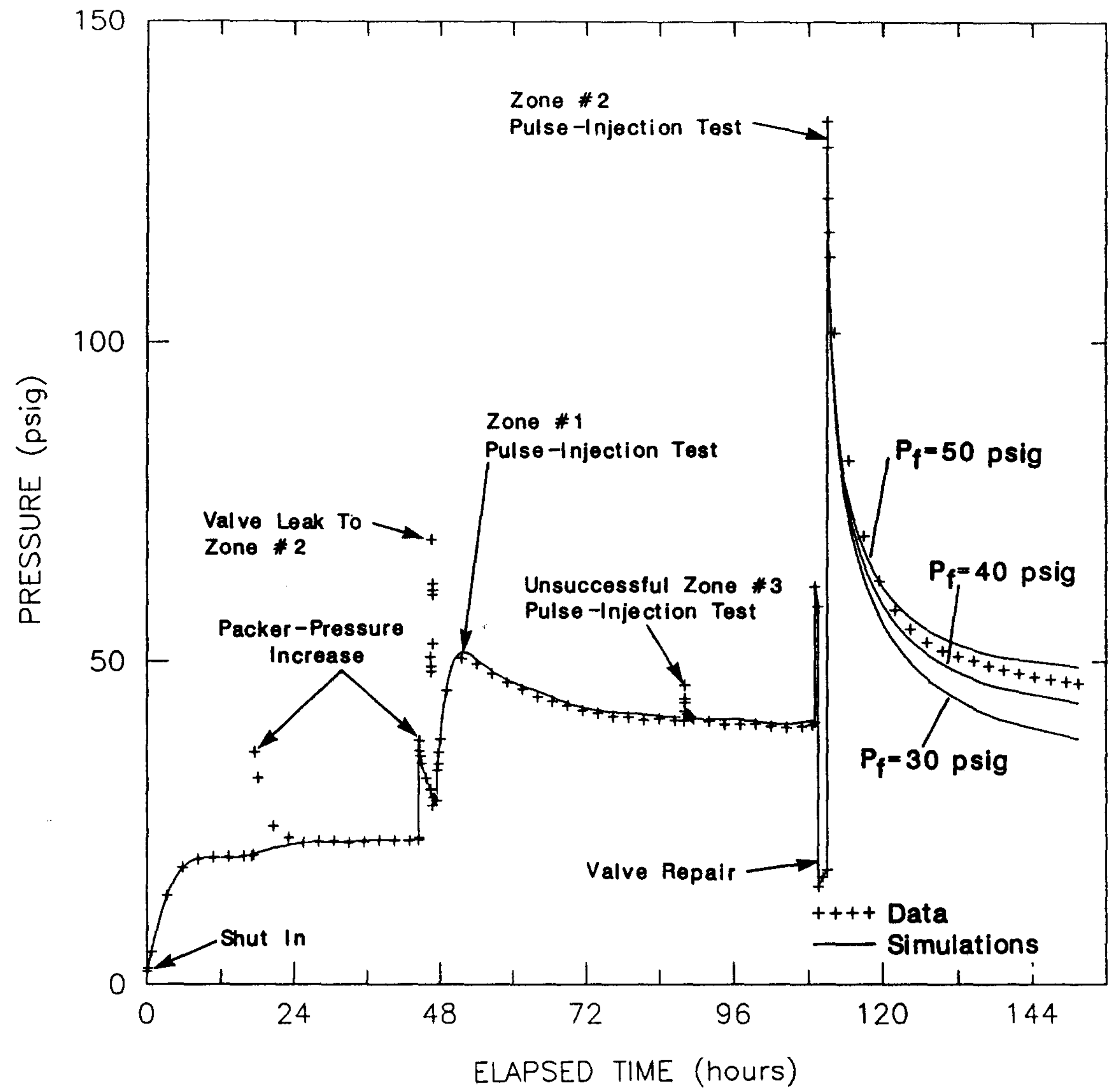



| Drawn by | Date |
|---|---|
| Checked by | Date |
| Revisions | Date |
| H09700R570 | |

Simulation of the Borehole W850W Zone #2 Pulse-Injection Test; Formation Pressure = 40 psig and Varying Hydraulic Conductivity

INTERA Technologies

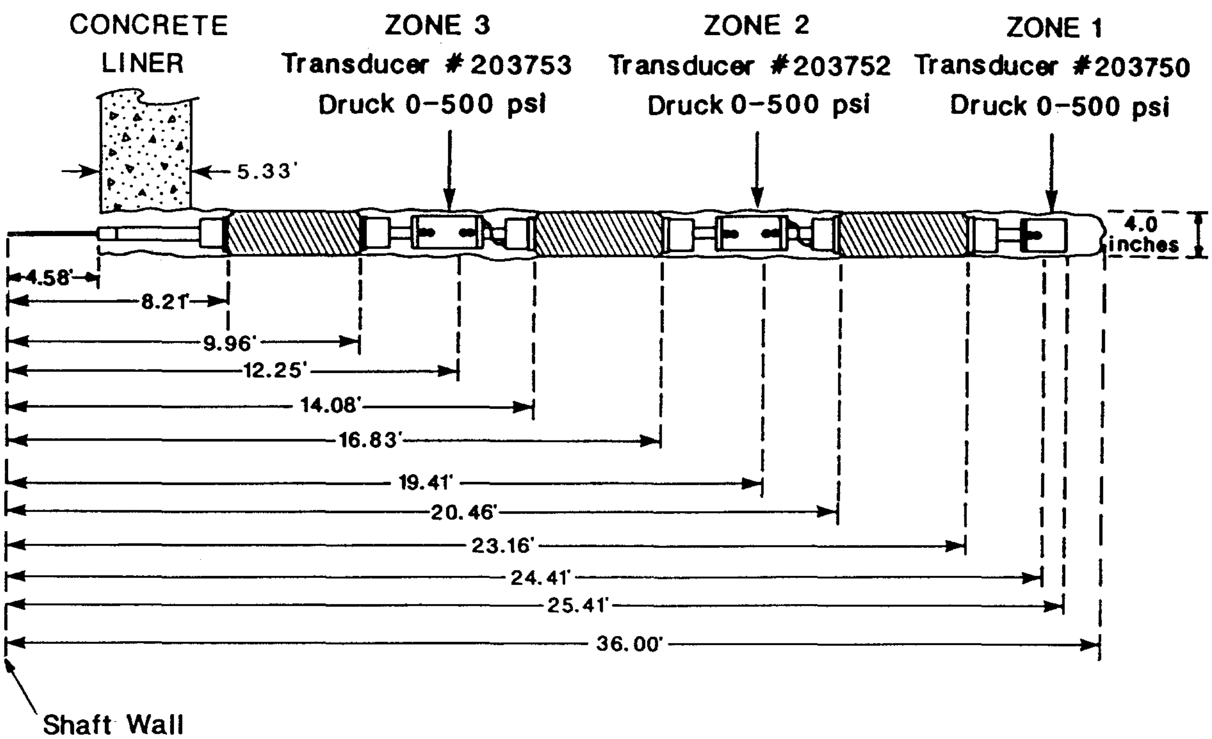
Figure 5.30




| | | |
|---|---|---|
| Drawn by | Date | Simulation of the Borehole W850W Zone #2 Pulse-Injection Test; Hydraulic Conductivity = 1.0 x $10^{-13}$ m/s and Varying Formation Pressure |
| Checked by | Date | |
| Revisions | Date | |
| H09700R570 | | |
| INTERA Technologies | | Figure 5.31 |

SHAFT LEVEL: 850 feet BGS

BOREHOLE LOCATION: W850SE (Southeast Wall)

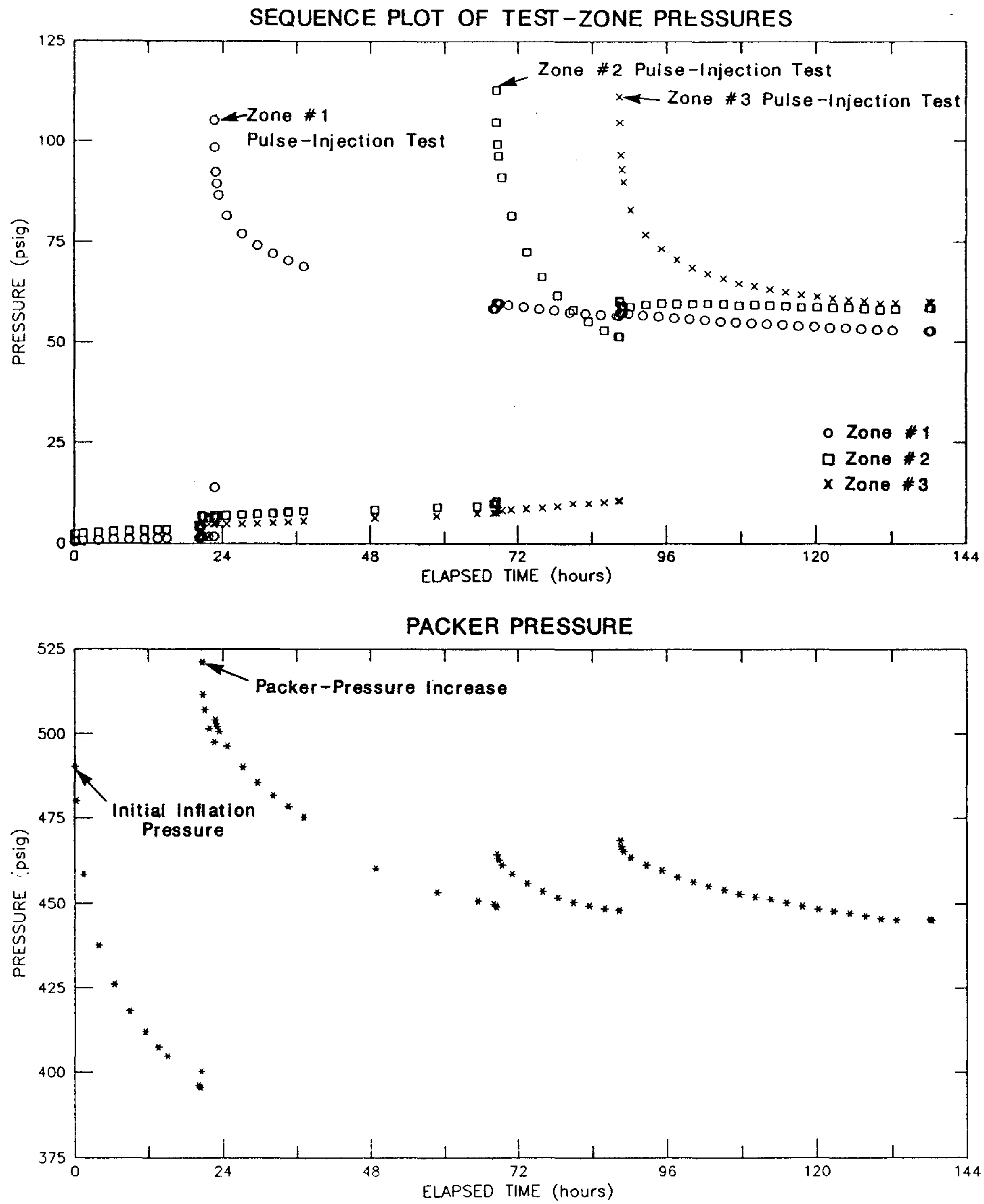



| Drawn by | Date |
|---|---|
| Checked by | Date |
| Revisions | Date |
| H09700R570 | |

Configuration of the Multipacker Test Tool in Borehole W850SE

INTERA Technologies

Figure 5.32




| Drawn by | Date |
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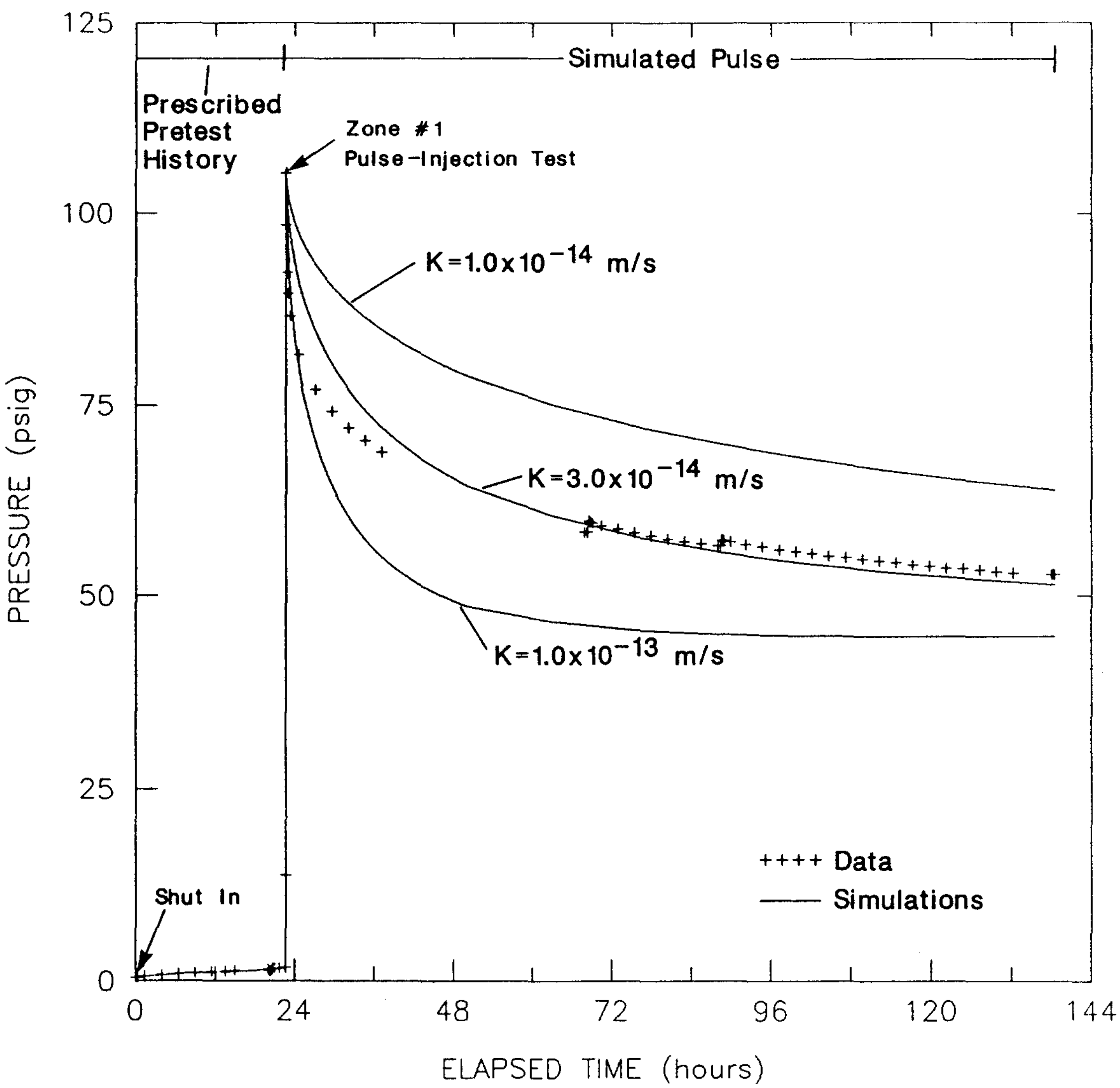
| Checked by | Date |
| Revisions | Date |
| H09700R570 | |

Linear-Linear Sequence Plot of the Test-Zone and Packer-Inflation Pressures During Testing in Borehole W850SE

INTERA Technologies

Figure 5.33

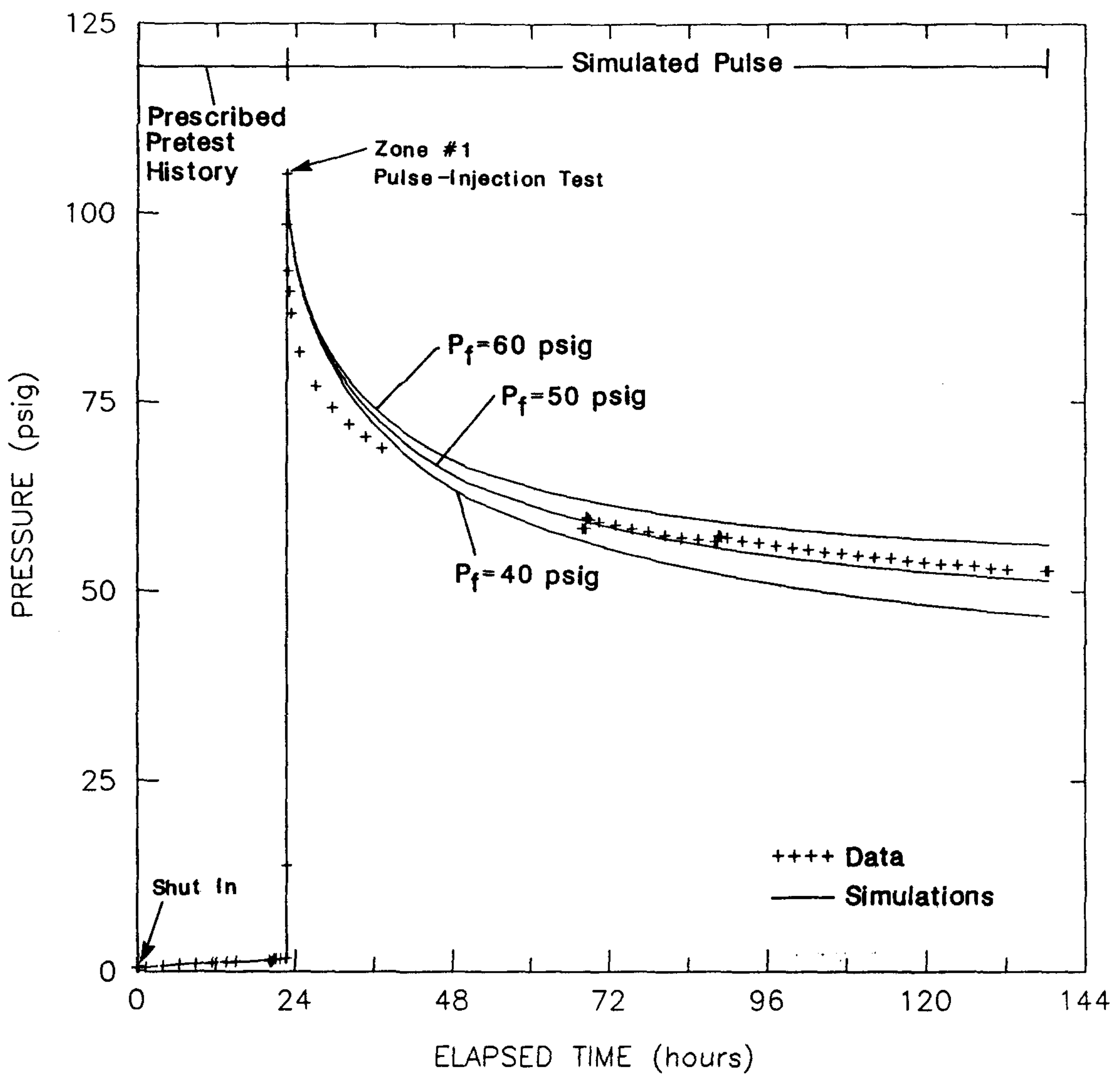



| Drawn by | Date |
|---|---|
| Checked by | Date |
| Revisions | Date |
| H09700R570 | |

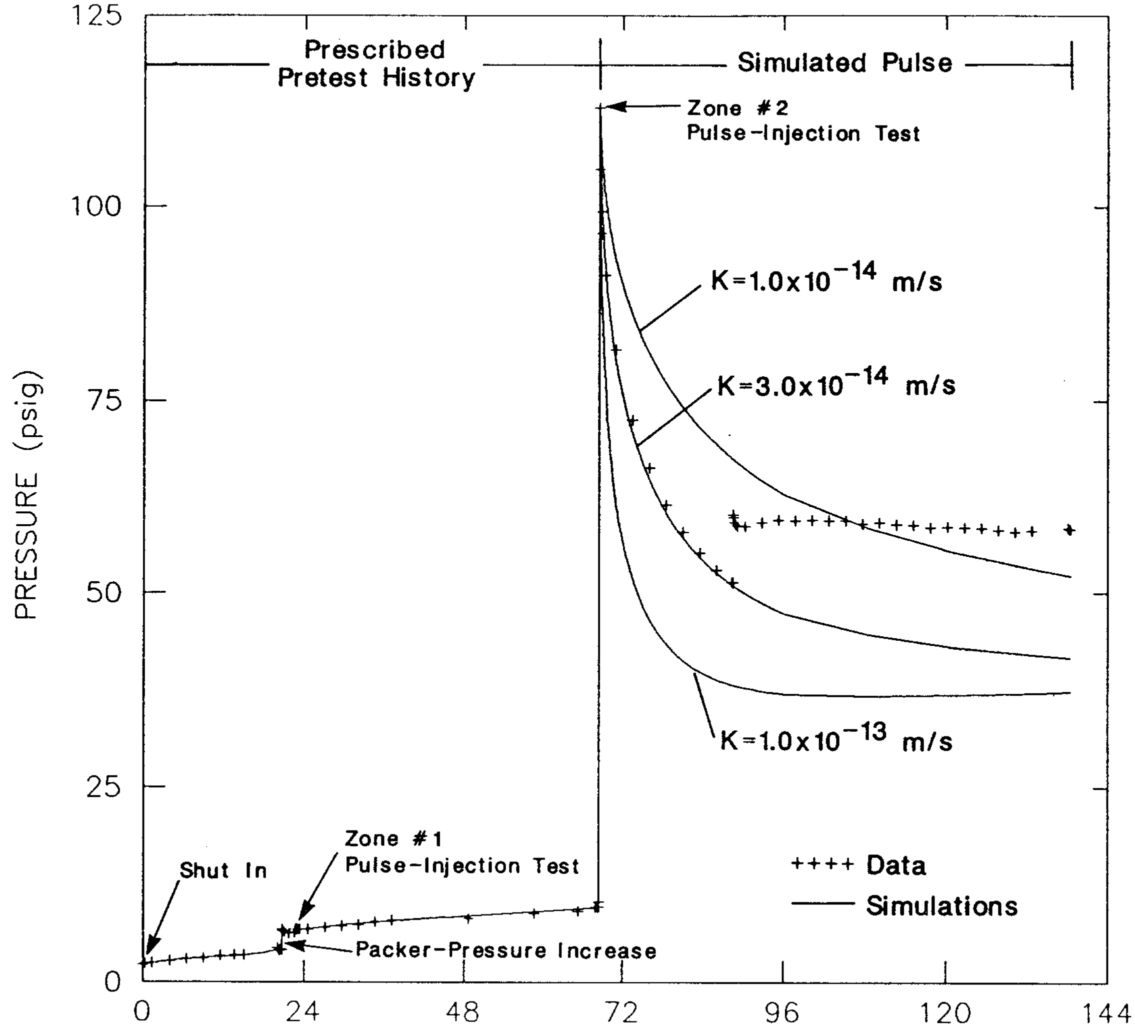
Simulation of the Borehole W850SE Zone #1 Pulse-Injection Test; Formation Pressure = 50 psig and Varying Hydraulic Conductivity

INTERA Technologies

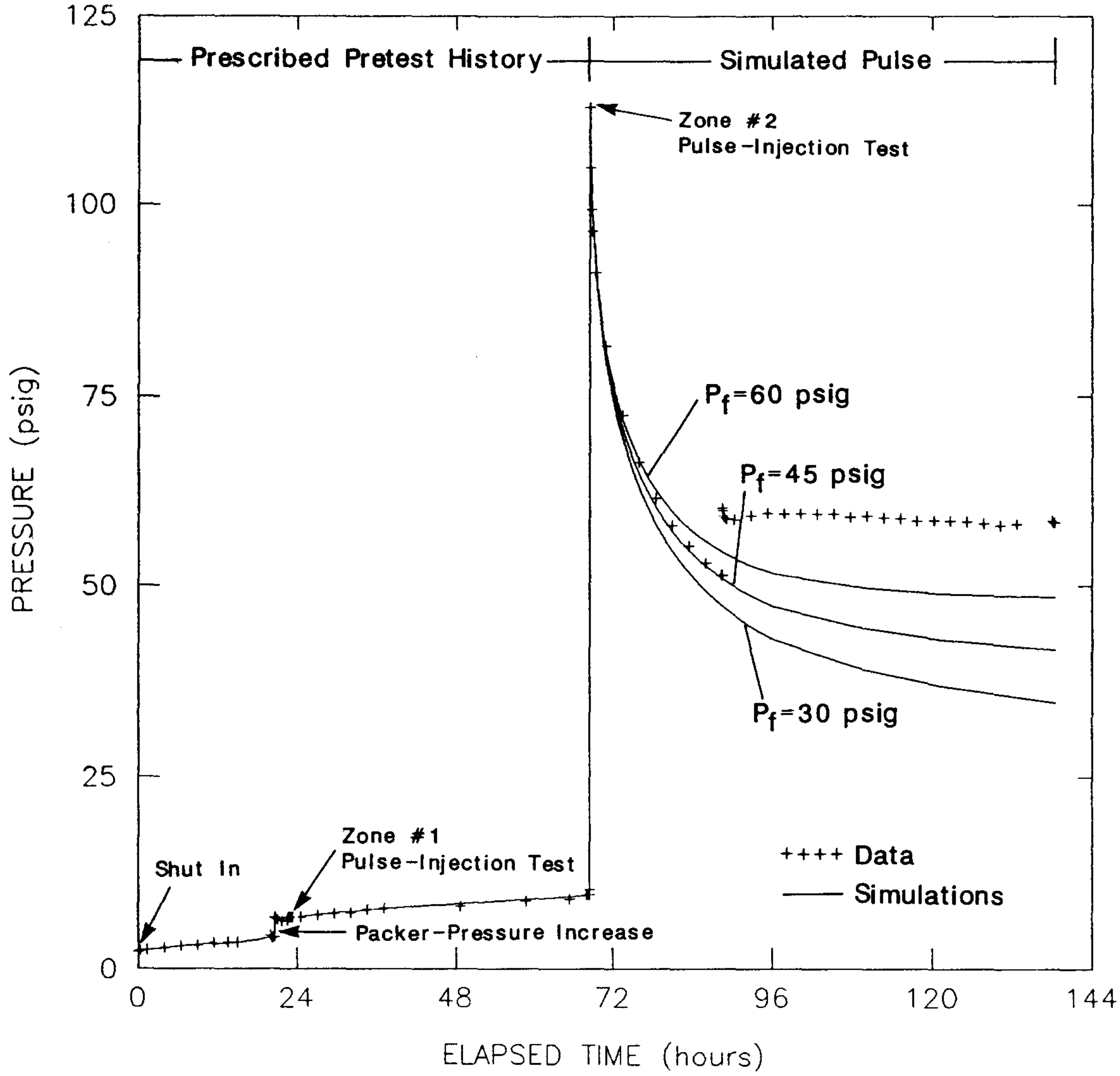
Figure 5.34




| | | |
|---|---|---|
| Drawn by | Date | Simulation of the Borehole W850SE Zone #1 Pulse-Injection Test; Hydraulic Conductivity = $3.0 \times 10^{-14}$ m/s and Varying Formation Pressure |
| Checked by | Date | |
| Revisions | Date | |
| H09700R570 | | |
| INTERA Technologies | | Figure 5.35 |




| | | |
|---|---|---|
| Drawn by | Date | Simulation of the Borehole W850SE Zone #2 Pulse-Injection Test; Formation Pressure = 45 psig and Varying Hydraulic Conductivity |
| Checked by | Date | |
| Revisions | Date | |
| H09700R570 | | |
| INTERA Technologies | | Figure 5.36 |

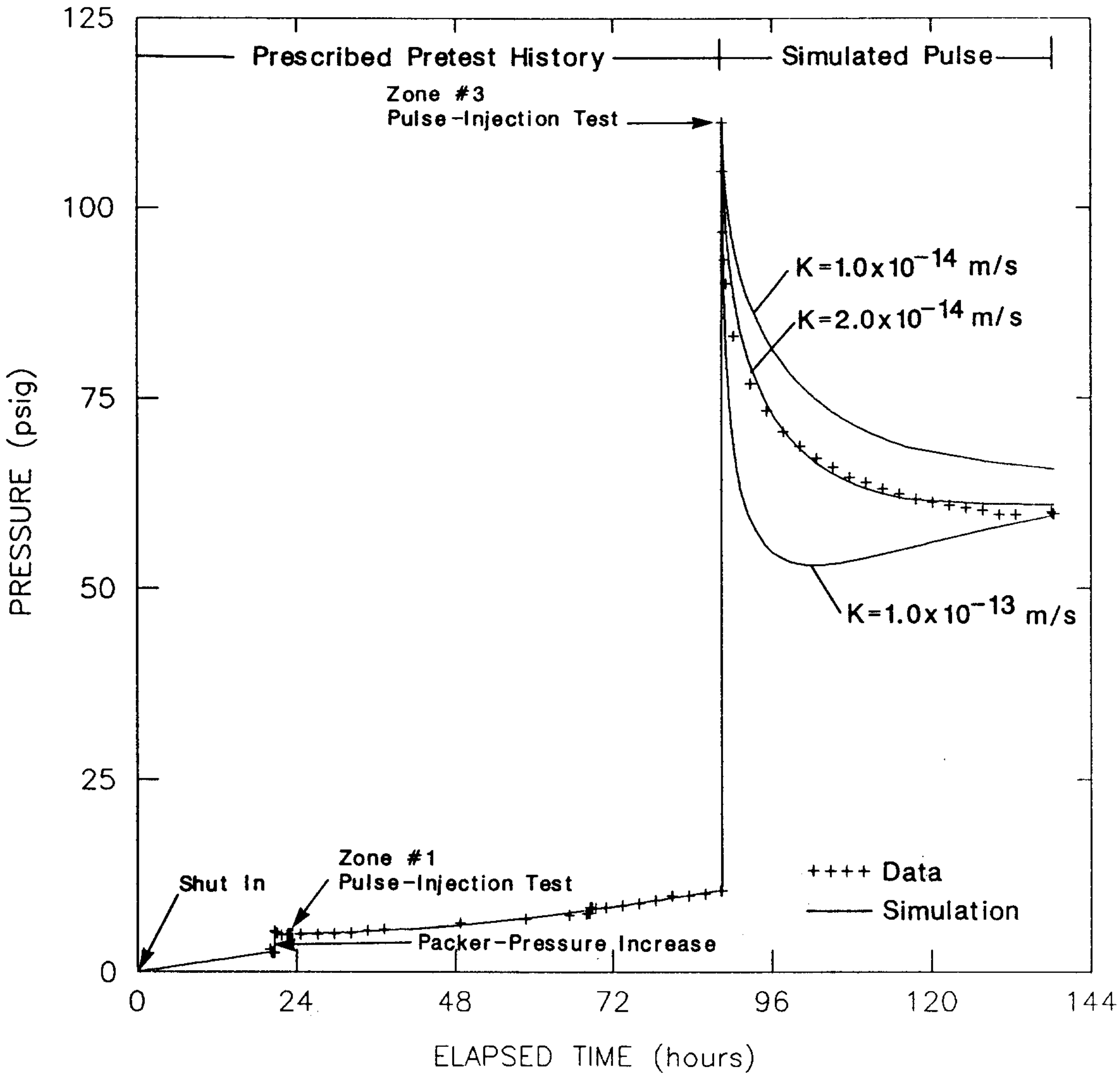



| Drawn by | Date |
|---|---|
| Checked by | Date |
| Revisions | Date |
| H09700R570 | |

INTERA Technologies

Simulation of the Borehole W850SE Zone #2 Pulse-Injection Test; Hydraulic Conductivity = $3.0 \times 10^{-14}$ m/s and Varying Formation Pressure

Figure 5.37

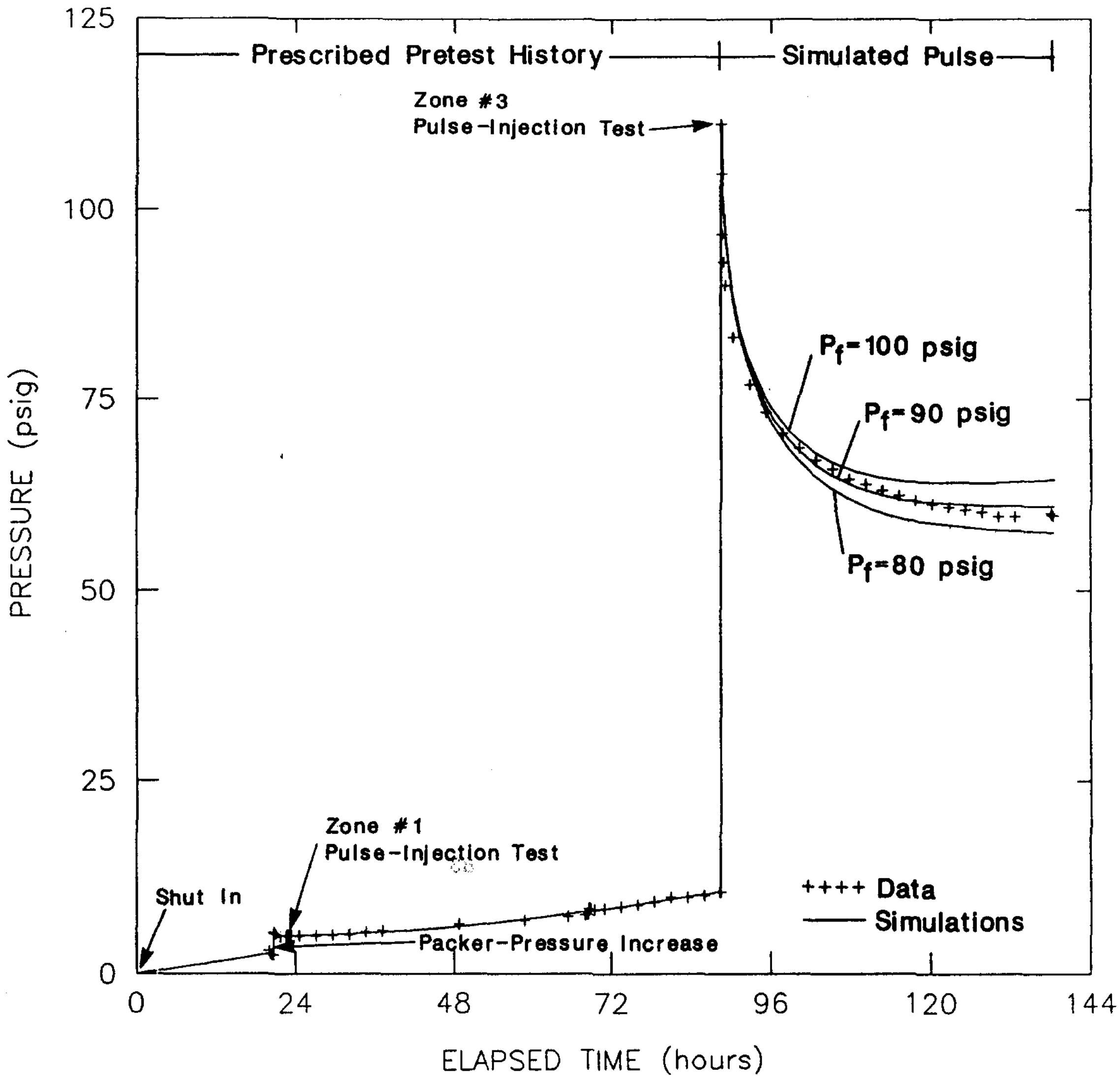



| Drawn by | Date |
|---|---|
| Checked by | Date |
| Revisions | Date |
| H09700R570 | |

Simulation of the Borehole W850SE Zone #3 Pulse-Injection Test; Formation Pressure = 90 psig and Varying Hydraulic Conductivity

INTERA Technologies

Figure 5.38




| | |
|---|---|
| Drawn by | Date |
| Checked by | Date |
| Revisions | Date |
| H09700R570 | |

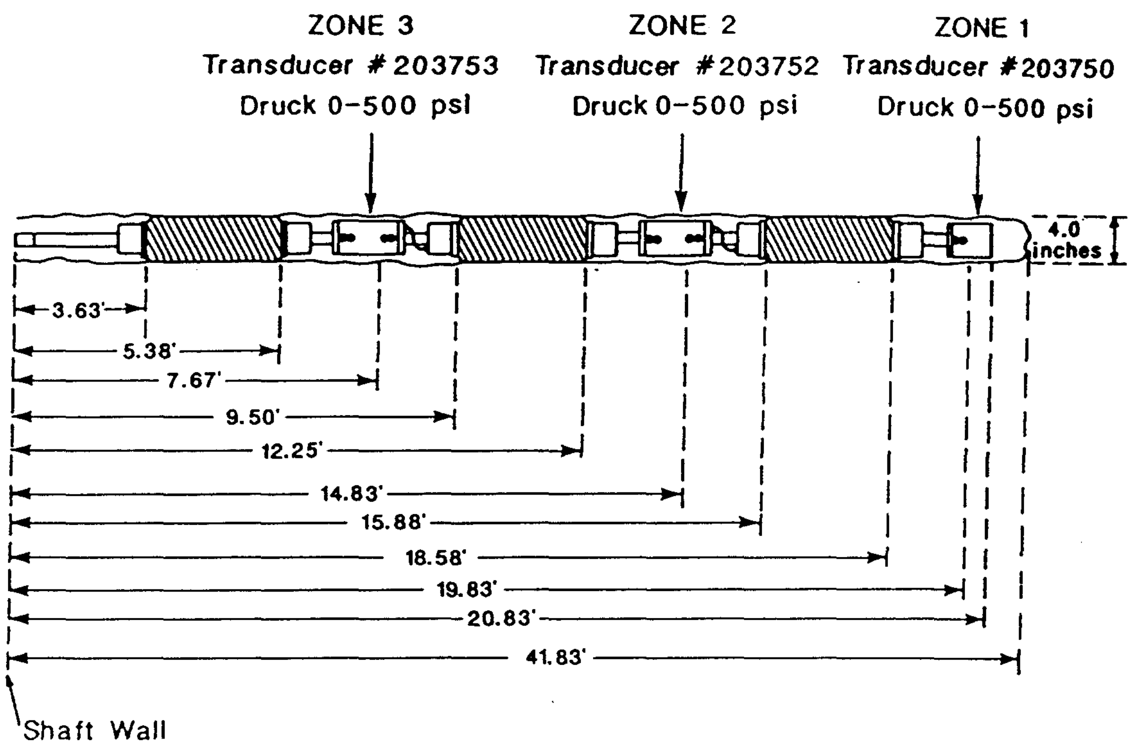
Simulation of the Borehole W850SE Zone #3 Pulse-Injection Test; Hydraulic Conductivity = $2.0 \times 10^{-14}$ m/s and Varying Formation Pressure

INTERA Technologies

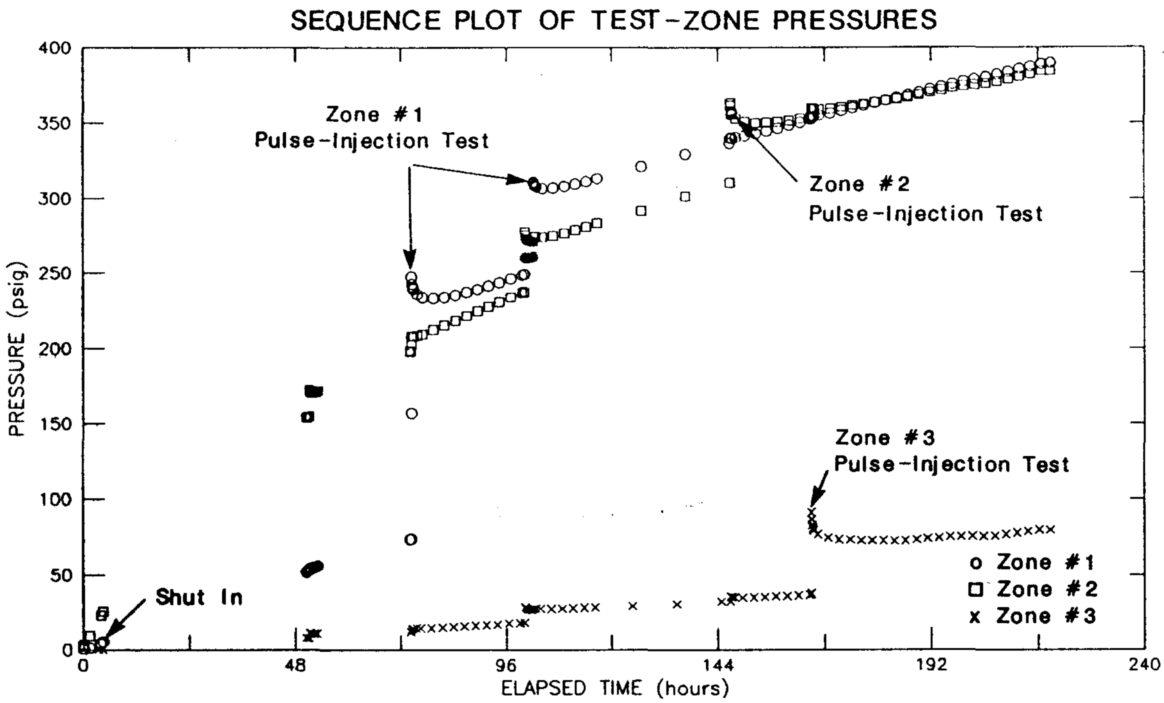
Figure 5.39

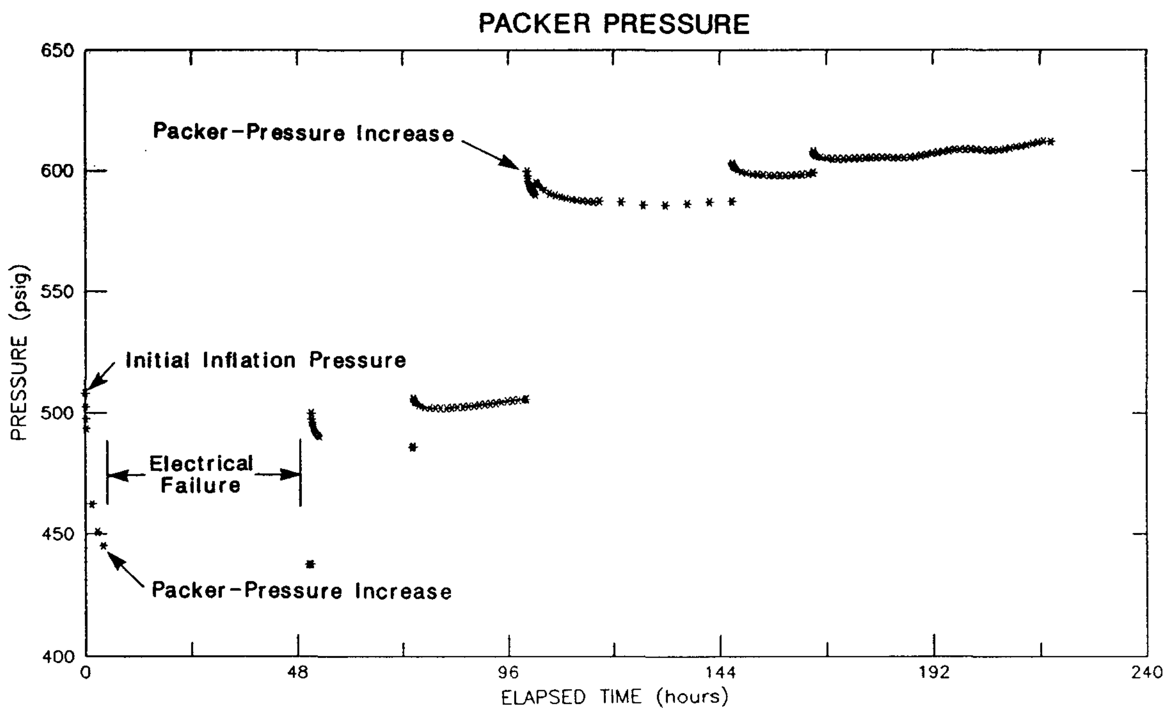
SHAFT LEVEL: 1320 feet BGS

BOREHOLE LOCATION: W1320E (East Wall)




| | | |
|---|---|---|
| Drawn by | Date | Configuration of the Multipacker Test Tool in Borehole W1320E |
| Checked by | Date | |
| Revisions | Date | |
| H09700R570 | | |
| INTERA Technologies | | Figure 5.40 |



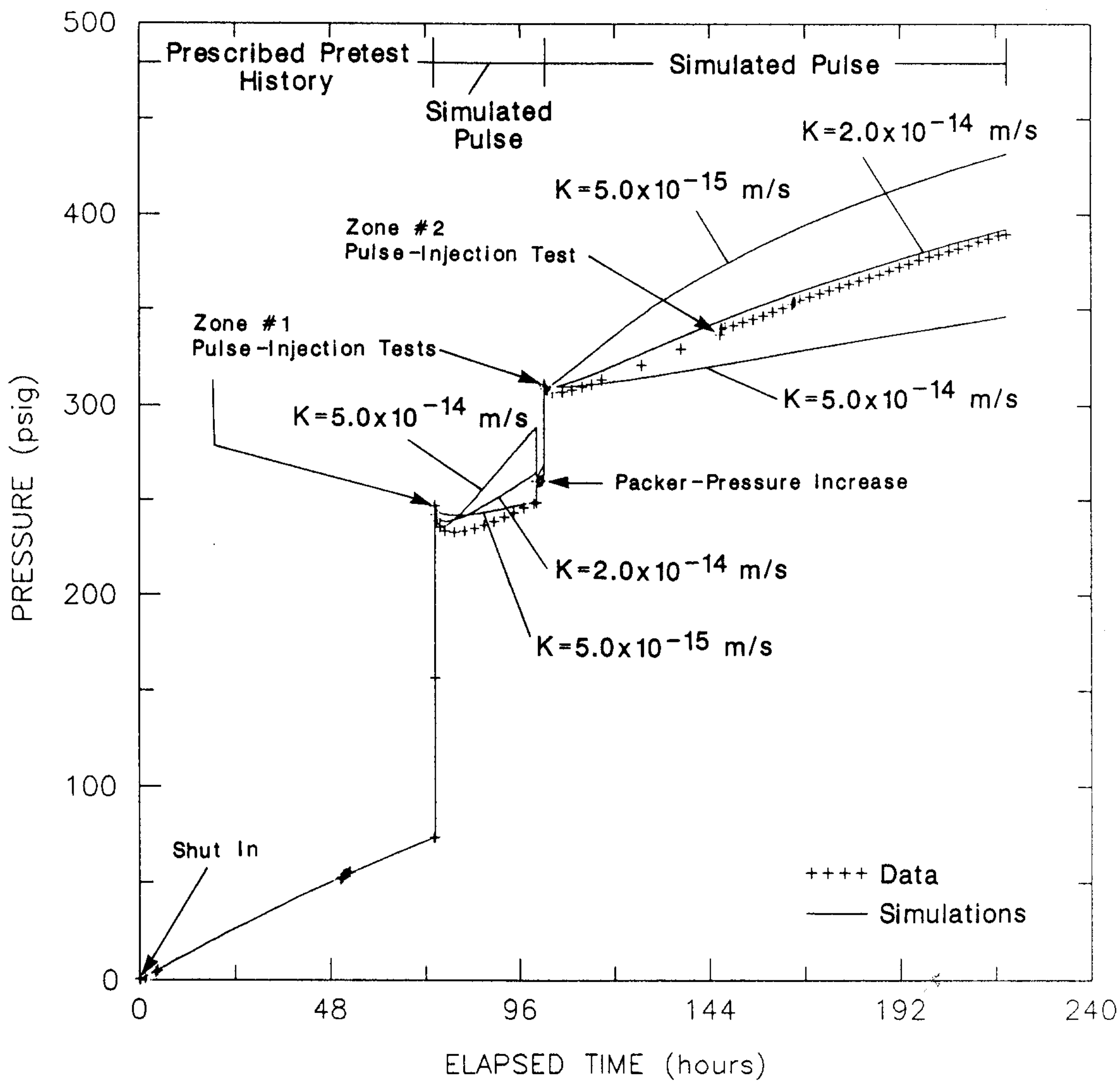




| Drawn by | Date |
|---|---|
| Checked by | Date |
| Revisions | Date |
| H09700R570 | |

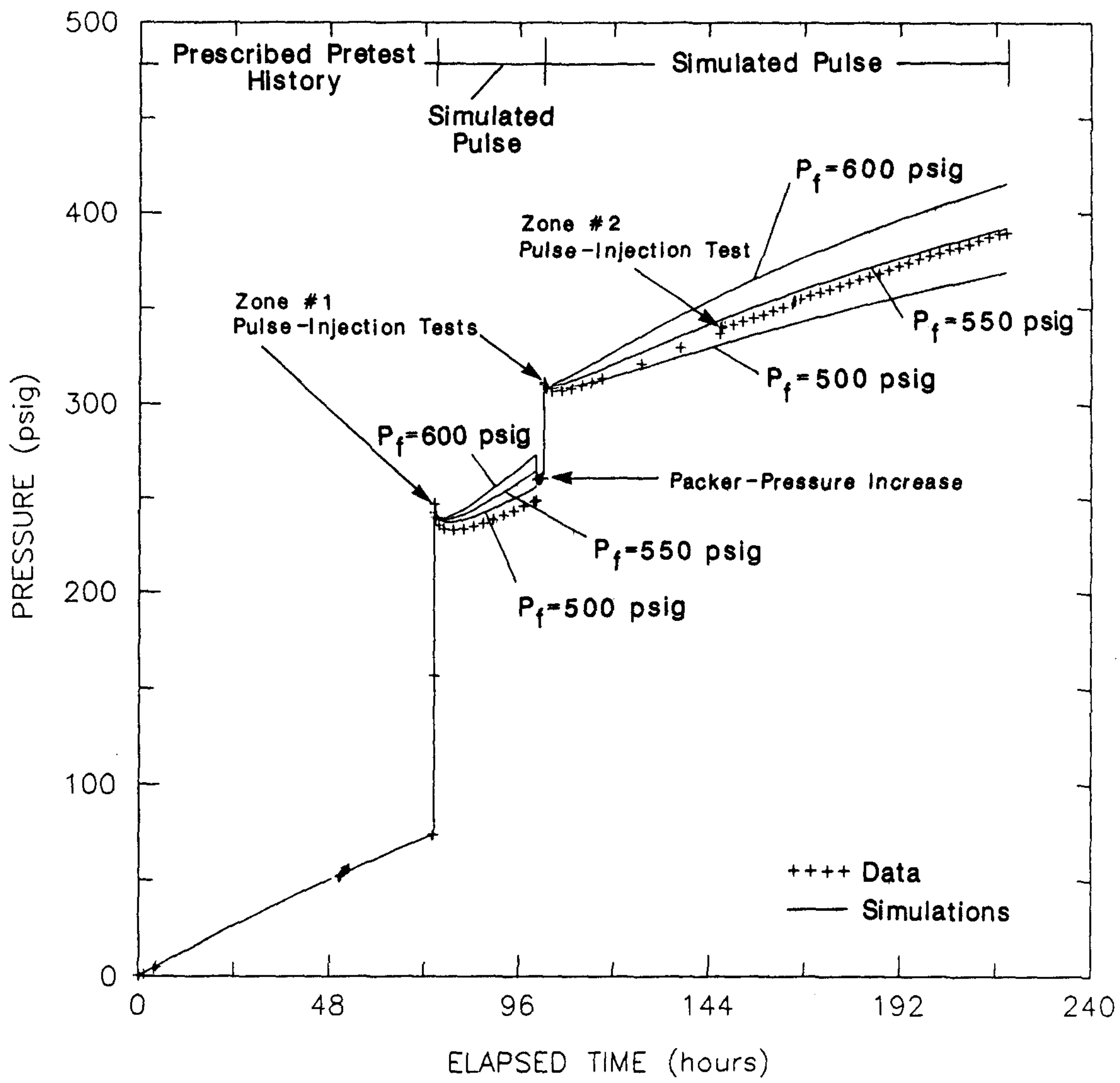
INTERA Technologies

Linear-Linear Sequence Plot of the Test-Zone and Packer-Inflation Pressures During Testing in Borehole W1320E

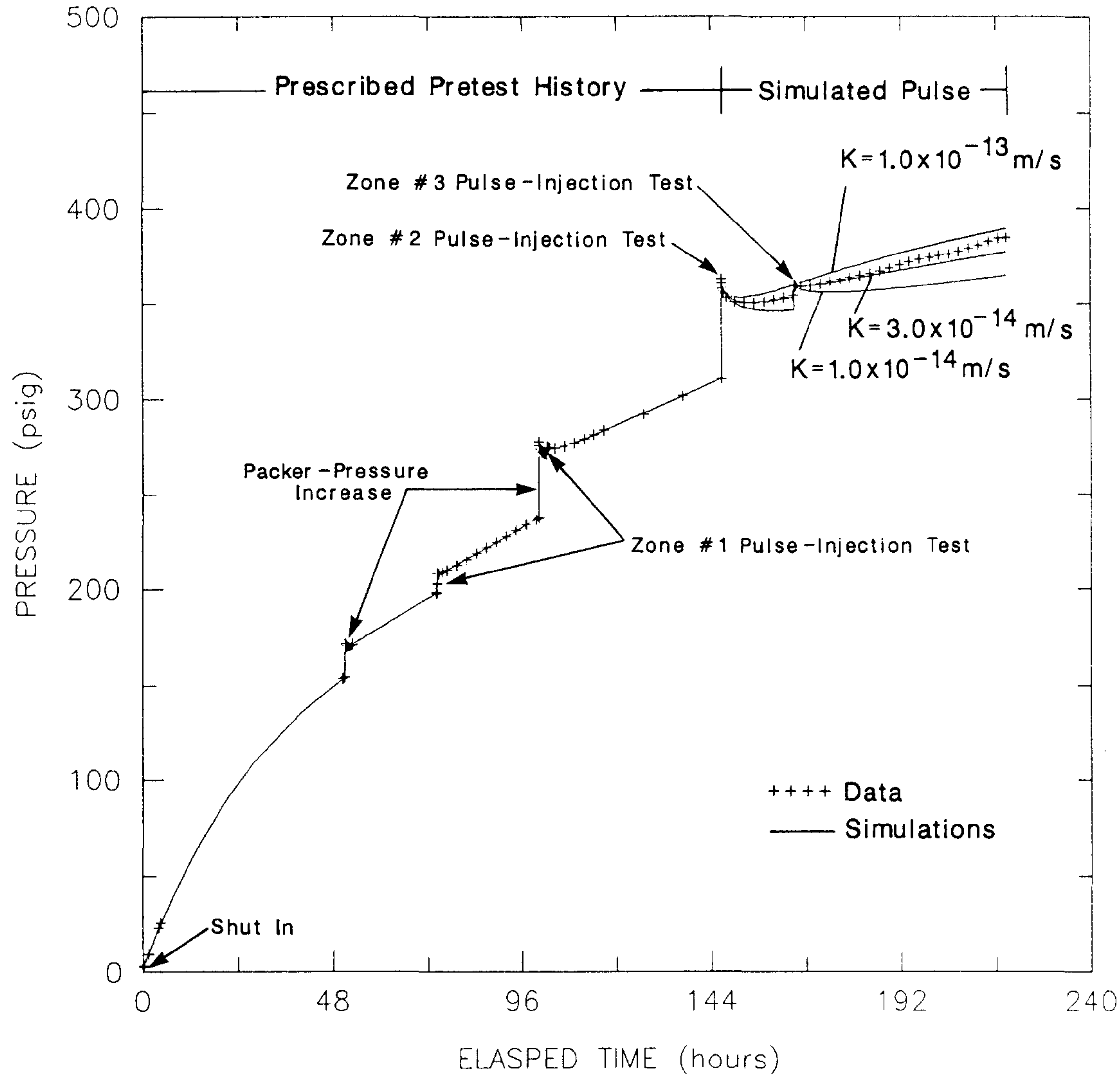
Figure 5.41




| Drawn by | Date | Simulation of the Borehole W1320E Zone #1 Pulse-Injection Tests; Formation Pressure = 550 psig and Varying Hydraulic Conductivity |
|---|---|---|
| Checked by | Date | |
| Revisions | Date | |
| H09700R570 | | |
| INTERA Technologies | | Figure 5.42 |




| Drawn by | Date | Simulation of the Borehole W1320E Zone #1 Pulse-Injection Tests; Hydraulic Conductivity = 2.0 x $10^{-14}$ m/s and Varying Formation Pressure |
|---|---|---|
| Checked by | Date | |
| Revisions | Date | |
| H09700R570 | | |
| INTERA Technologies | | Figure 5.43 |

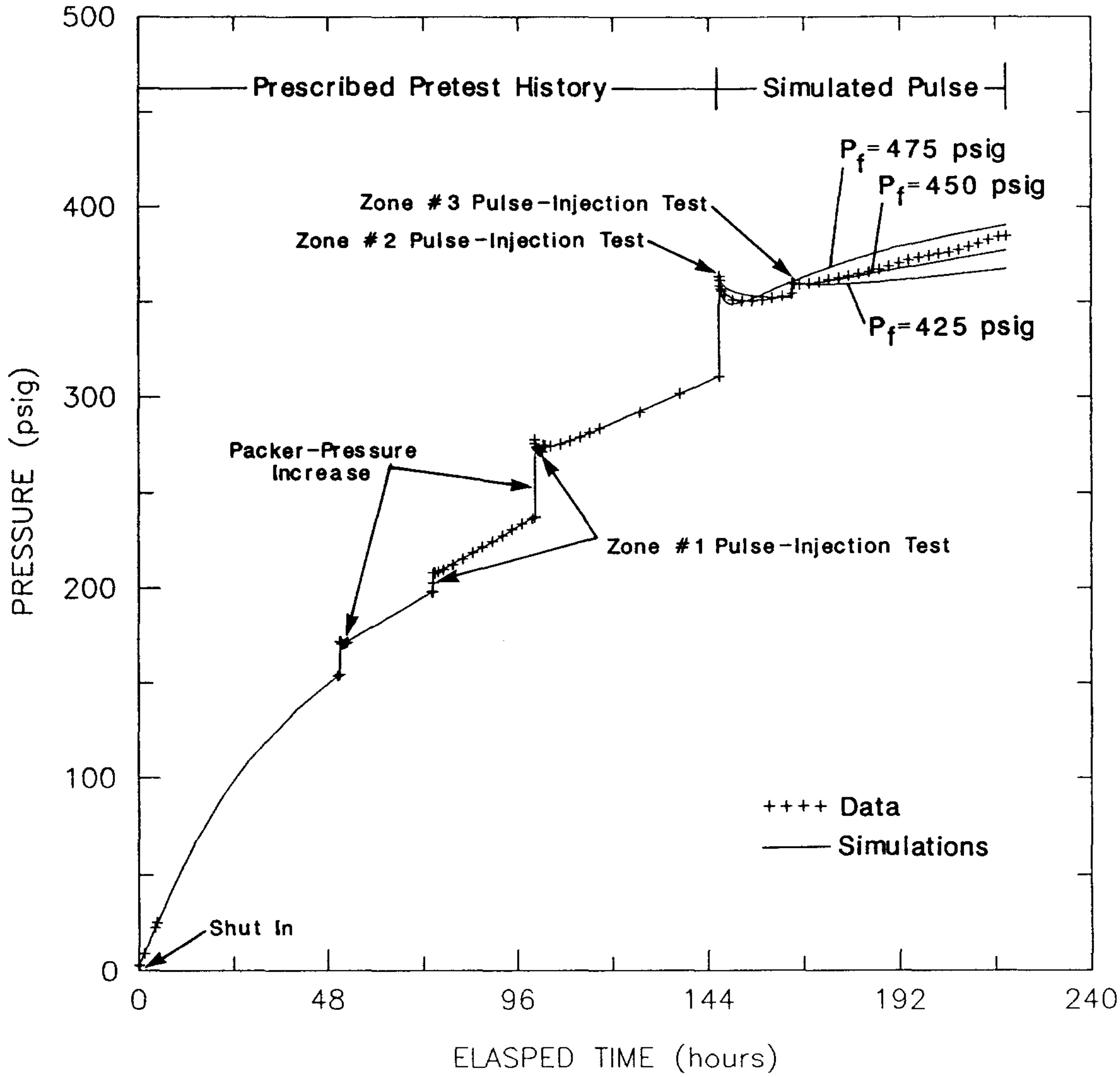



| Drawn by | Date |
|---|---|
| Checked by | Date |
| Revisions | Date |
| H09700R570 | |

Simulation of the Borehole W1320E Zone #2 Pulse-Injection Test; Formation Pressure = 500 psig and Varying Hydraulic Conductivity

INTERA Technologies

Figure 5.44

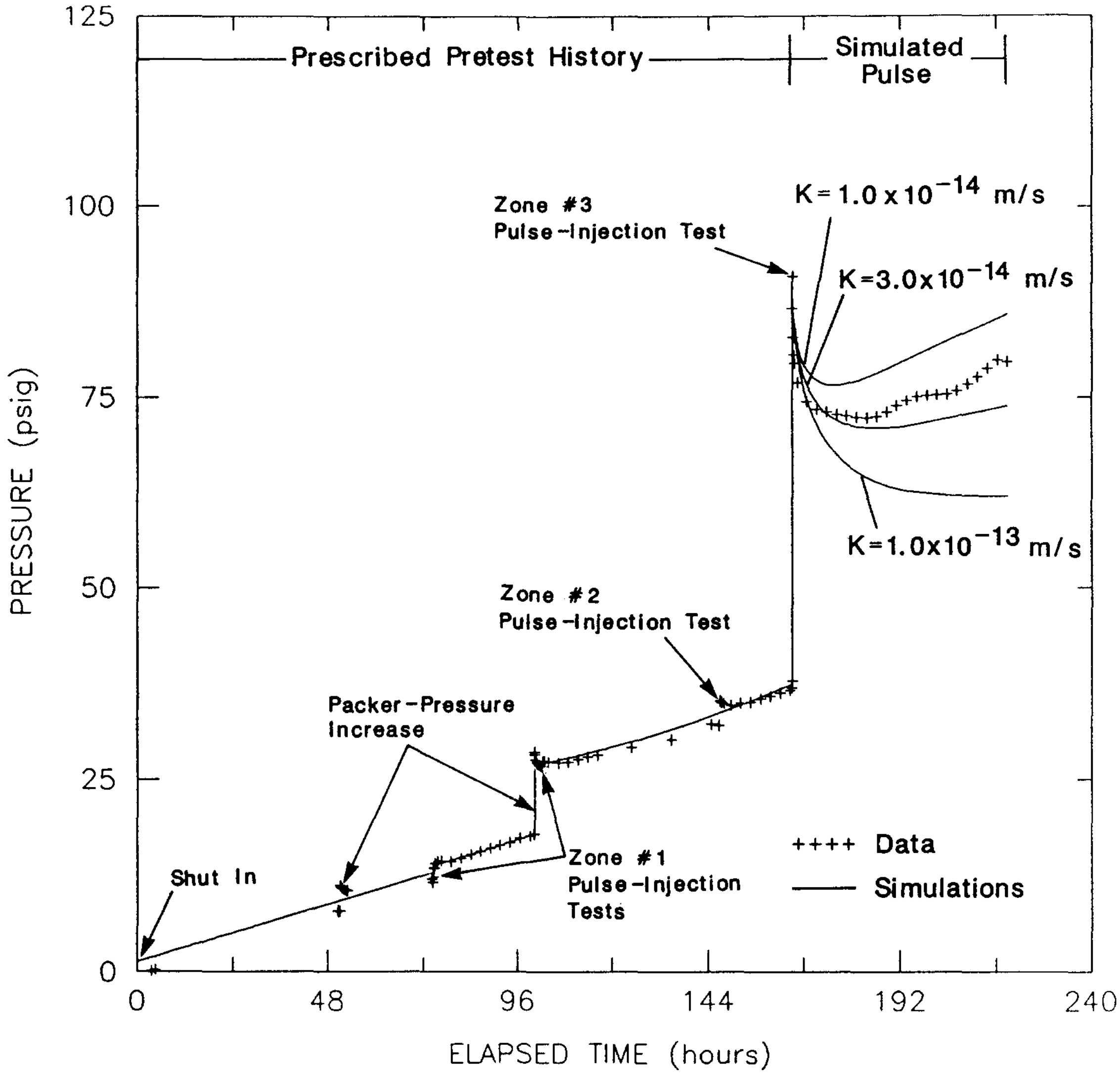



| Drawn by | Date |
|---|---|
| Checked by | Date |
| Revisions | Date |
| H09700R570 | |

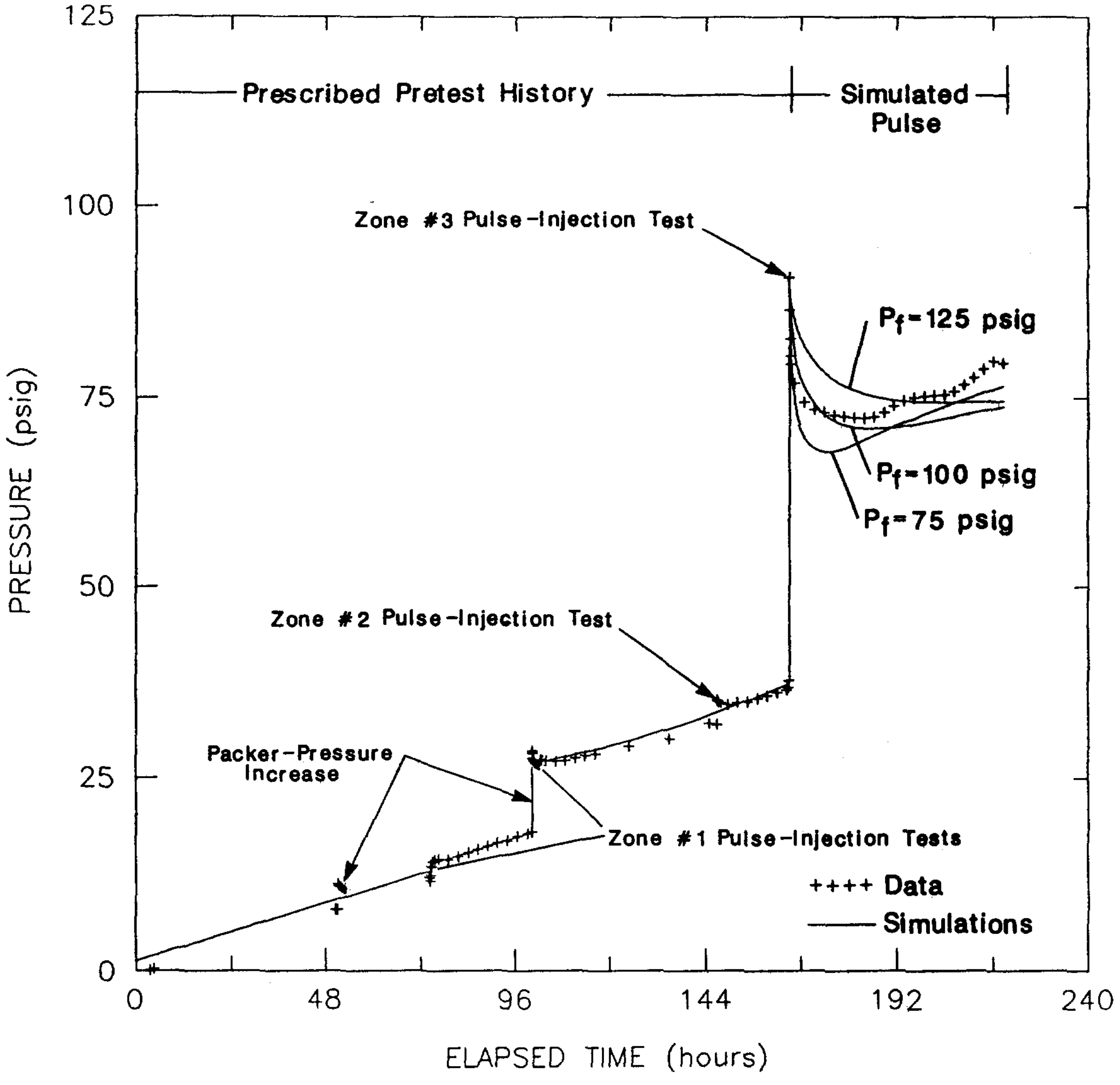
Simulation of the Borehole W1320E Zone #2 Pulse-Injection Test; Hydraulic Conductivity = 3.0 x $10^{-14}$m/s and Varying Formation Pressure

INTERA Technologies

Figure 5.45




| Drawn by | Date | Simulation of the Borehole W1320E Zone #3 Pulse-Injection Test; Formation Pressure = 100 psig and Varying Hydraulic Conductivity |
| --- | --- | --- |
| Checked by | Date | |
| Revisions | Date | |
| H09700R570 | | |
| INTERA Technologies | | Figure 5.46 |

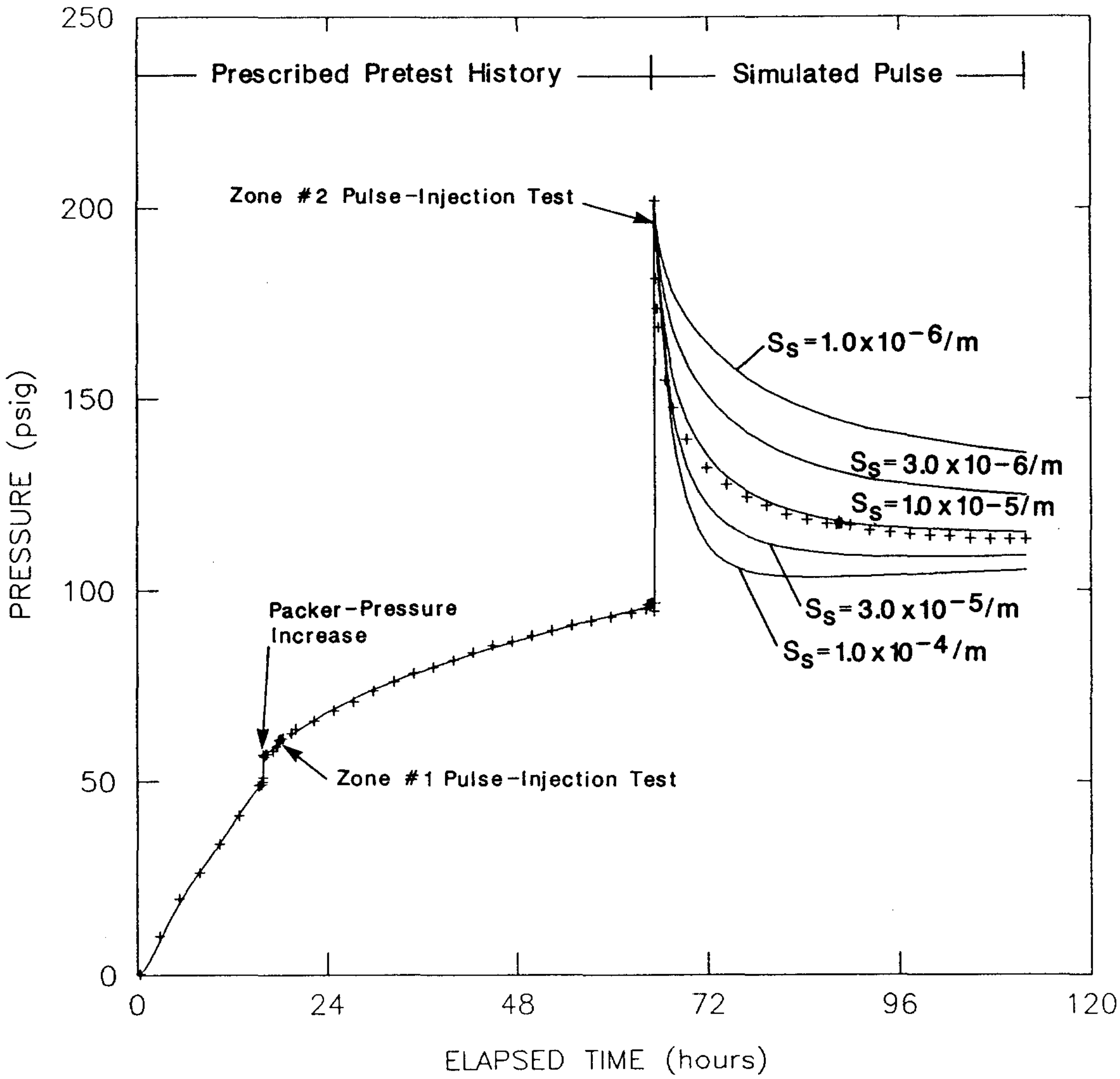



| Drawn by | Date |
|---|---|
| Checked by | Date |
| Revisions | Date |
| H09700R570 | |

Simulation of the Borehole W1320E Zone #3 Pulse-Injection Test; Hydraulic Conductivity = $3.0 \times 10^{-14}$ m/s and Varying Formation Pressure

INTERA Technologies

Figure 5.47

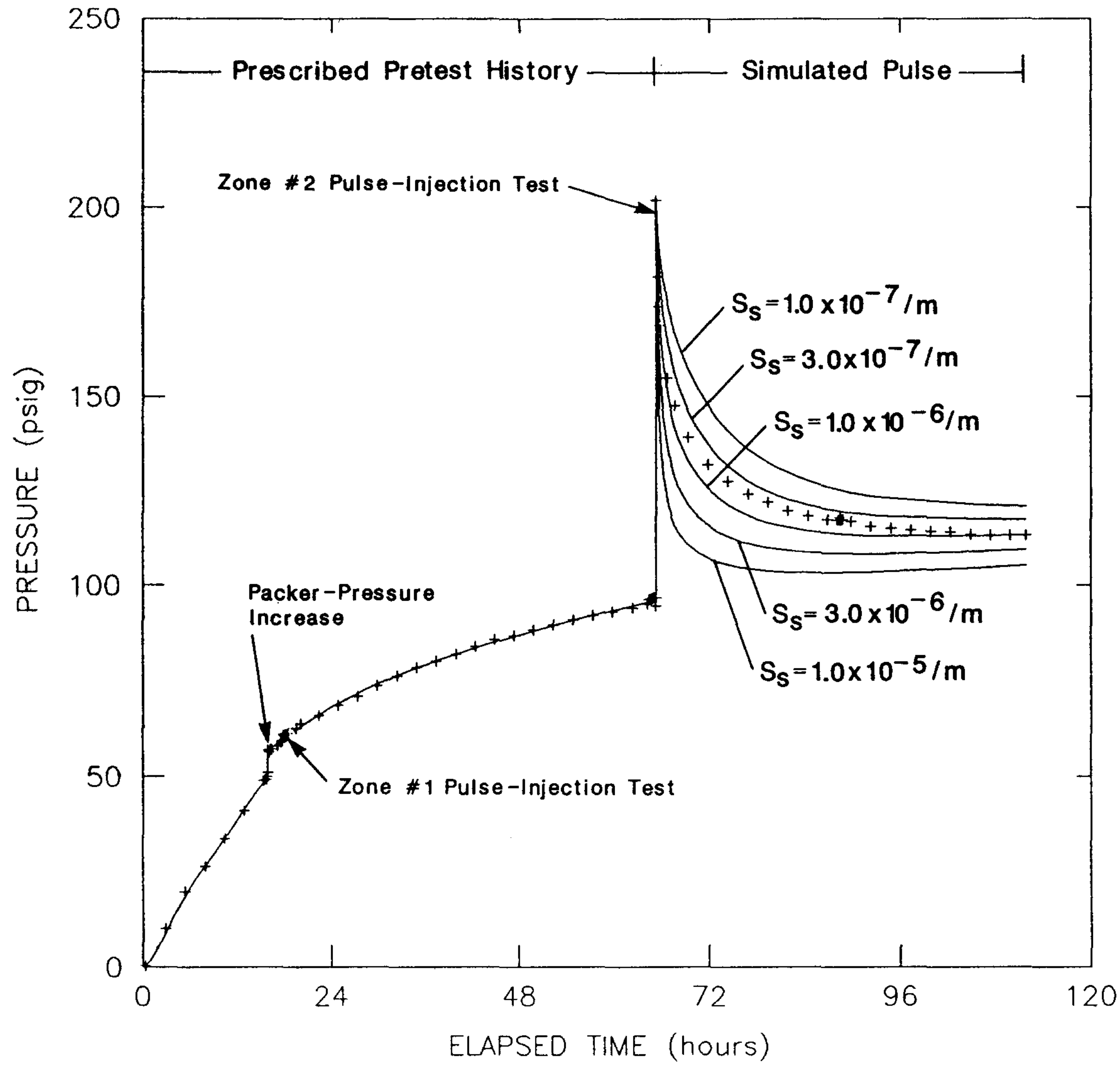



| Drawn by | Date |
|---|---|
| Checked by | Date |
| Revisions | Date |
| H09700R570 | |

Simulation of the Borehole W805E Zone #2 Pulse-Injection Test; Hydraulic Conductivity=$1.0 \times 10^{-14}$ m/s, Formation Pressure=140 psig, and Varying Specific Storage

INTERA Technologies

Figure 5.48

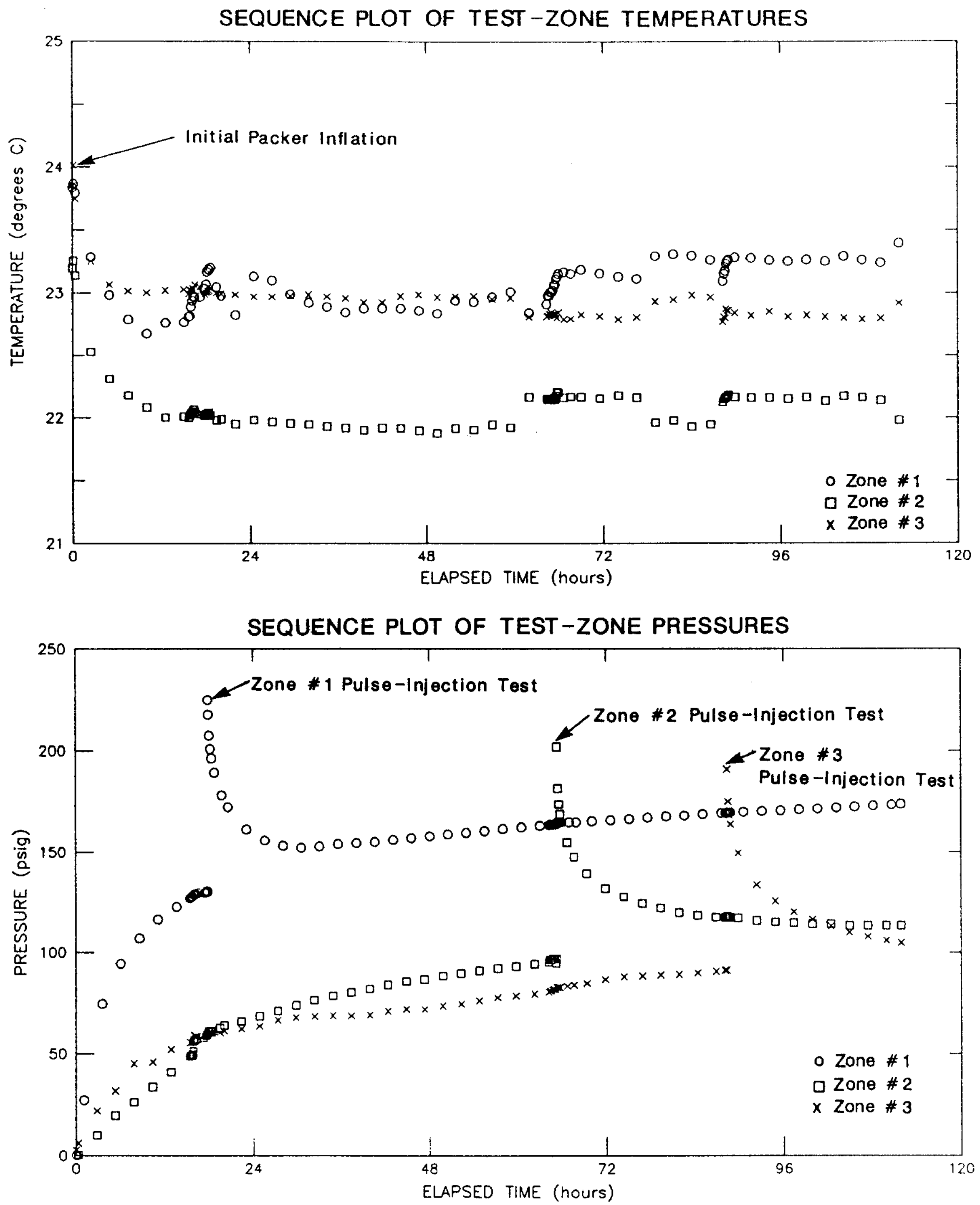



| Drawn by | Date |
|---|---|
| Checked by | Date |
| Revisions | Date |
| H09700R570 | |

Simulation of the Borehole W805E Zone #2 Pulse-Injection Test; Hydraulic Conductivity= $1.0\times10^{-13}$ m/s, Formation Pressure=130 psig, and Varying Specific Storage

INTERA Technologies

Figure 5.49

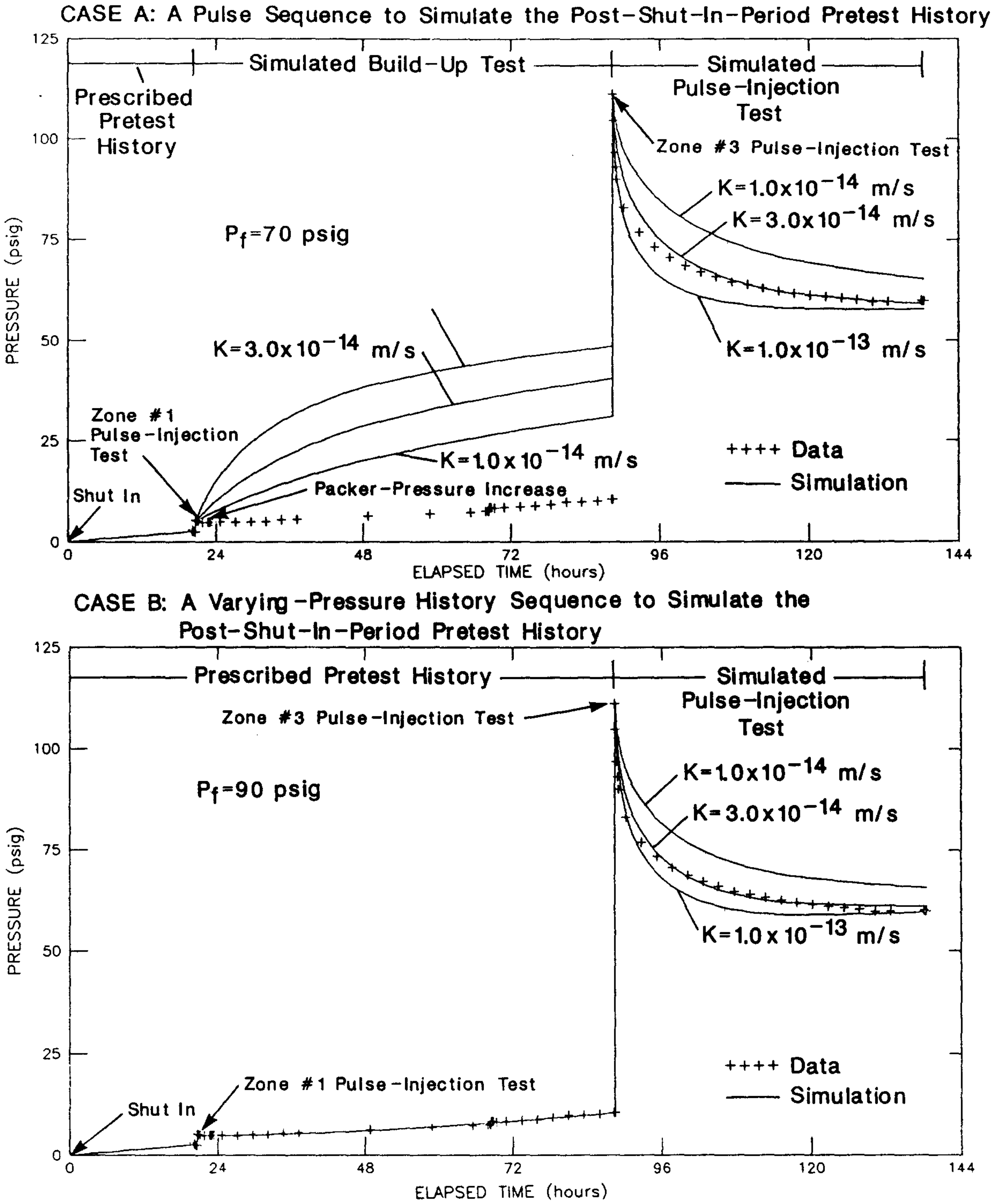



| Drawn by | Date |
|---|---|
| Checked by | Date |
| Revisions | Date |
| H09700R570 | |

Linear-Linear Sequence Plot of the Test-Zone Temperatures and Pressures During Testing in Borehole W805E

INTERA Technologies

Figure 5.50

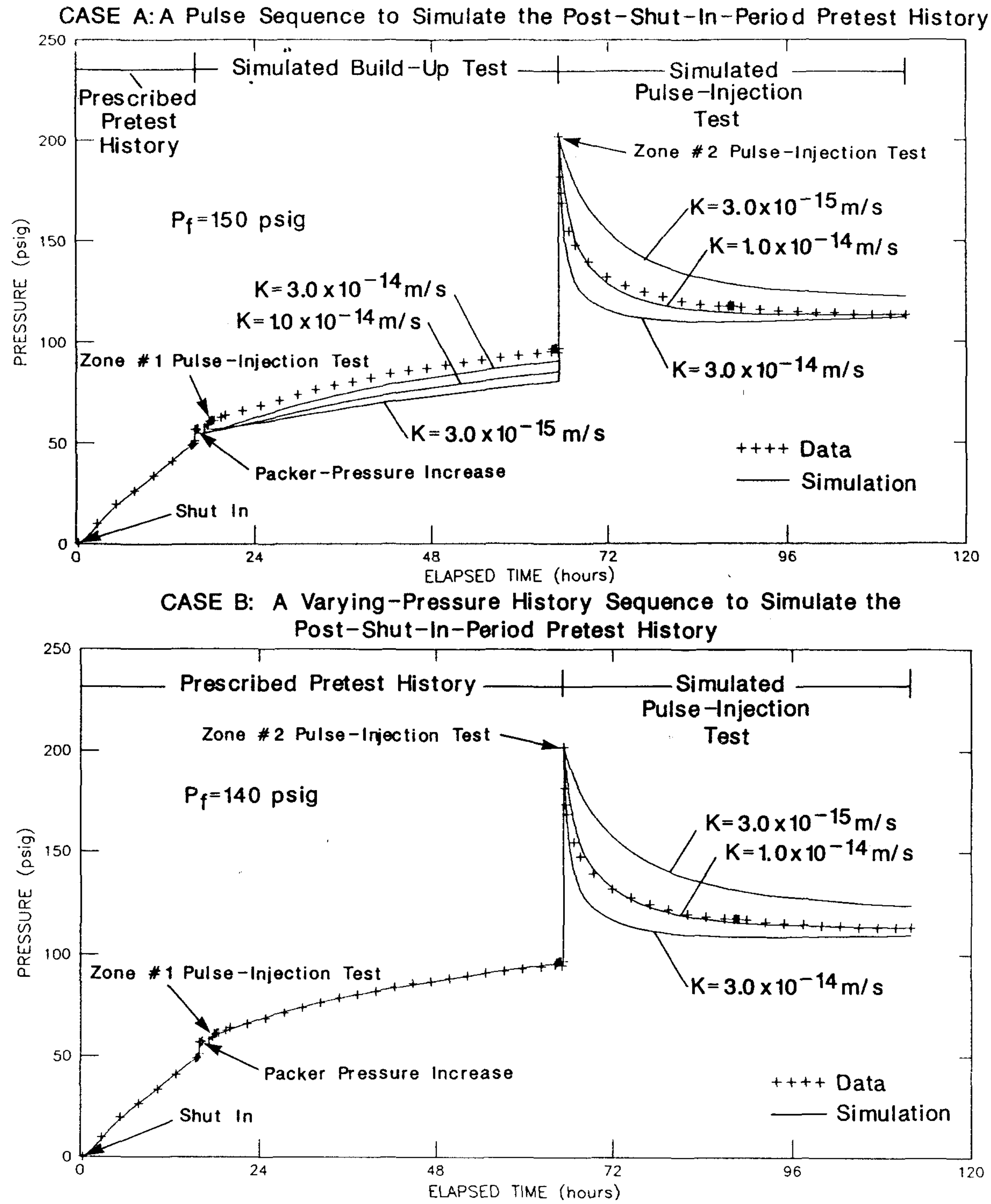



| | |
|---|---|
| Drawn by | Date |
| Checked by | Date |
| Revisions | Date |
| H09700R570 | |

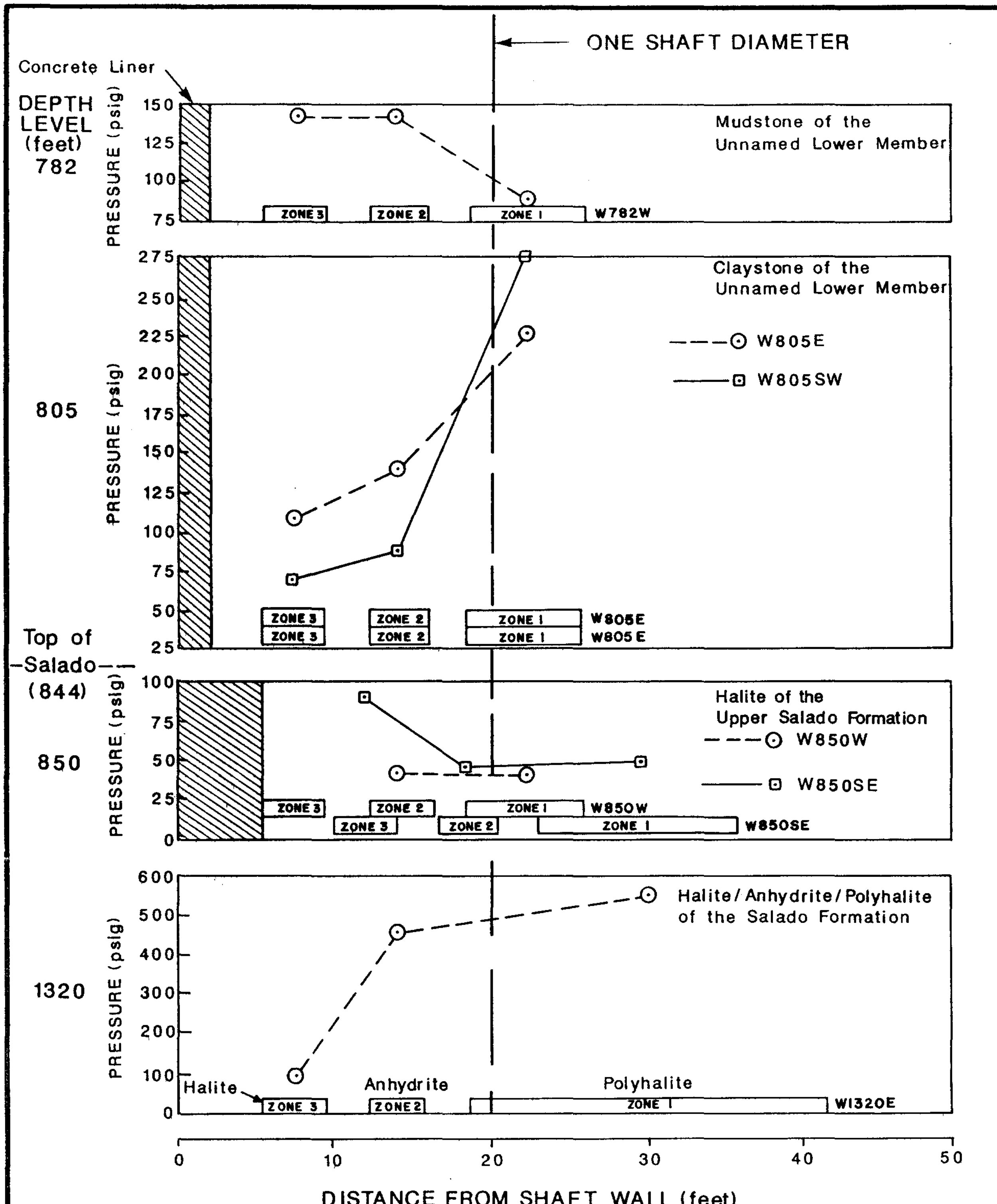
Comparison of the Simulations of the Borehole W850SE Zone #2 Pulse-Injection Test Using Case A and Case B

INTERA Technologies

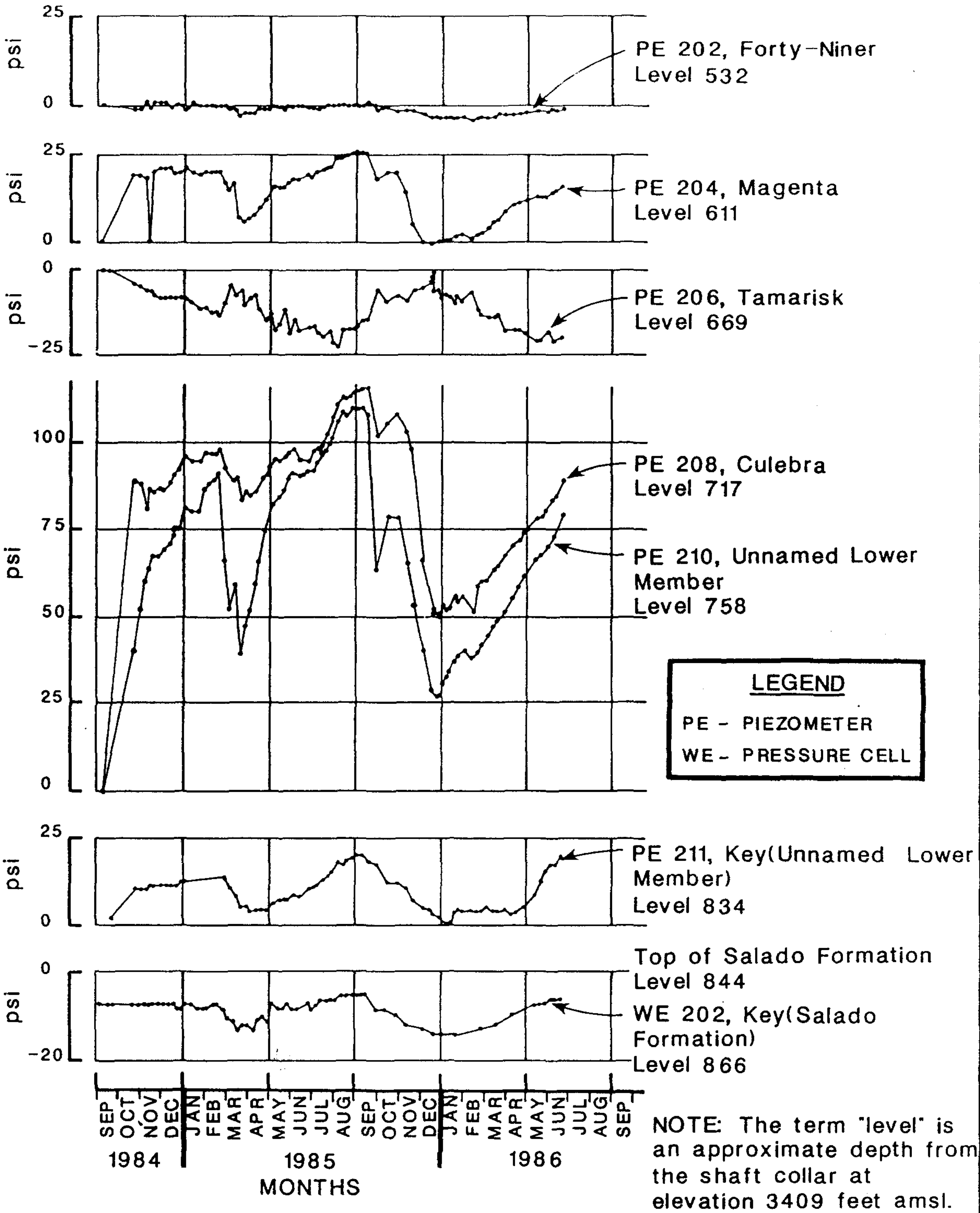
Figure 5.51




| | | |
|---|---|---|
| Drawn by | Date | Comparison of the Simulations of the Borehole W805E Zone #2 Pulse-Injection Test Using Case A and Case B |
| Checked by | Date | |
| Revisions | Date | |
| H09700R570 | | |
| INTERA Technologies | | Figure 5.52 |




| | | |
|---|---|---|
| Drawn by | Date | Estimated Formation Pressure vs Distance from the Shaft Wall in the Six Boreholes Tested in the Waste-Handling Shaft |
| Checked by | Date | |
| Revisions | Date | |
| H09700R570 | | |
| INTERA Technologies | | Figure 6.1 |



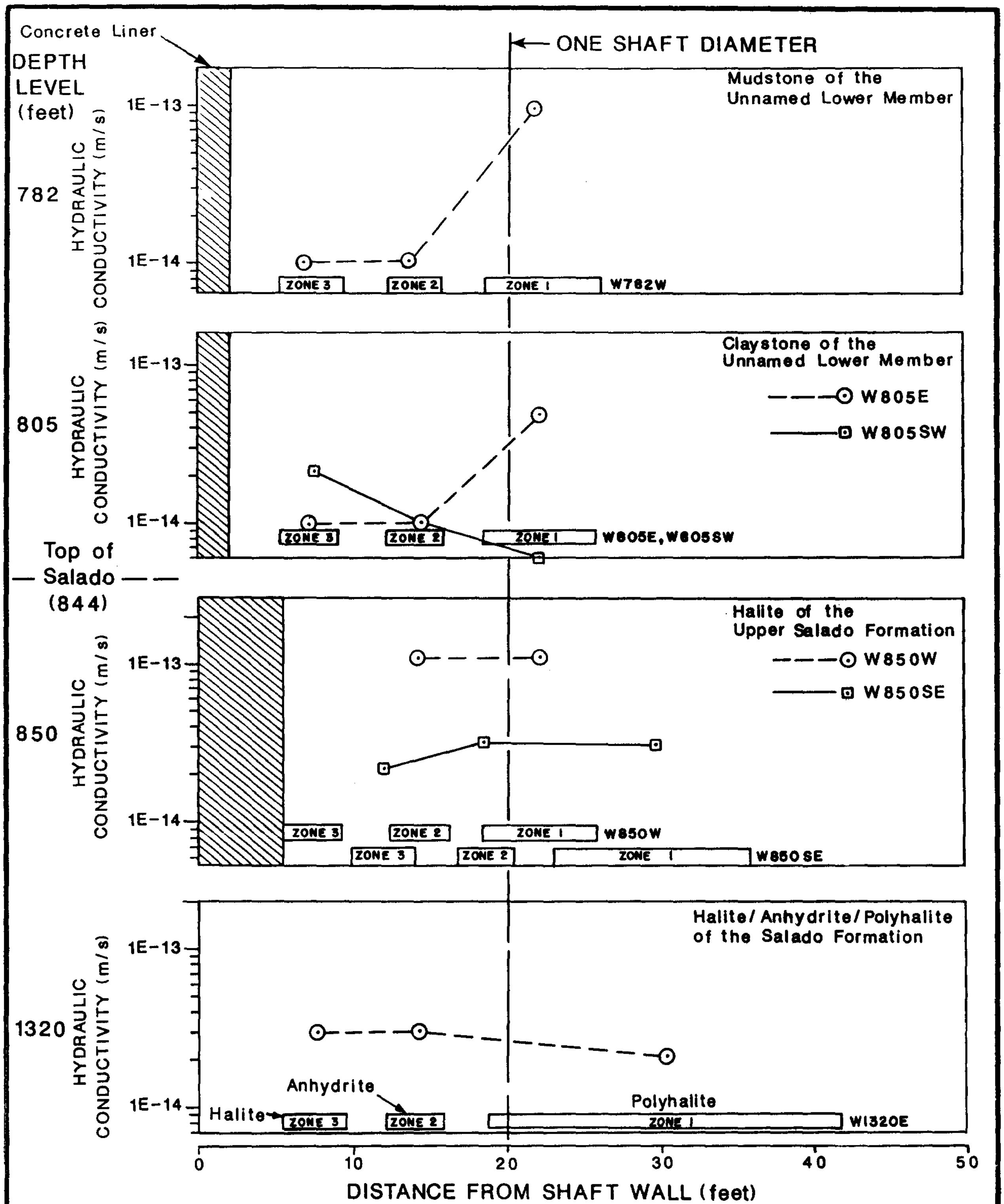

NOTE: The term "level" is an approximate depth from the shaft collar at elevation 3409 feet amsl.

| | |
|---|---|
| Drawn by | Date |
| Checked by | Date |
| Revisions | Date |
| H09700R570 | |

Records of Responses of Piezometers and a Pressure Cell in the Waste-Handling Shaft (Data from Bechtel, 1986)

INTERA Technologies

Figure 6.2




| Drawn by | Date |
|---|---|
| Checked by | Date |
| Revisions | Date |
| H09700R570 | |

Estimated Hydraulic Conductivity vs Distance from the Shaft Wall in the Six Boreholes Tested in the Waste-Handling Shaft

INTERA Technologies

Figure 6.3

| BOREHOLE | ZONE # | TEST INTERVAL (feet) | INTERVAL MIDPOINT (feet) | TIME OF DRILLING OF INTERVAL MIDPOINT |
|---|---|---|---|---|
| W782W | 1 | 18.58 - 26.00 | 22.29 | 0150 July 16 |
| | 2 | 12.25 - 15.88 | 14.07 | 0030 July 16 |
| | 3 | 5.38 - 9.50 | 7.44 | 2350 July 15 |
| W805E | 1 | 18.58 - 26.00 | 22.29 | 0030 July 09 |
| | 2 | 12.25 - 15.88 | 14.07 | 2315 July 08 |
| | 3 | 5.38 - 9.50 | 7.44 | 2220 July 08 |
| W805SW | 1 | 18.58 - 26.50 | 22.54 | 2230 August 22 |
| | 2 | 12.25 - 15.88 | 14.07 | 2150 August 22 |
| | 3 | 5.38 - 9.50 | 7.44 | 2045 August 22 |
| W850W | 1 | 18.58 - 26.00 | 22.29 | 2340 July 24 |
| | 2 | 12.25 - 15.88 | 14.07 | 2305 July 24 |
| | 3 | 5.38 - 9.50 | 7.44 | 2235 July 24 |
| W850SE | 1 | 23.16 - 36.00 | 29.58 | 0050 August 05 |
| | 2 | 16.80 - 20.05 | 18.43 | 2230 August 04 |
| | 3 | 10.00 - 14.10 | 12.01 | 2100 August 04 |
| W1320E | 1 | 18.58 - 41.83 | 30.21 | 0030 August 08 |
| | 2 | 12.25 - 15.88 | 14.07 | 2150 August 07 |
| | 3 | 5.38 - 9.50 | 7.44 | 2045 August 07 |

NOTE: Distances measured from shaft wall

| Drawn by | Date | Estimated Times When the Center of the Test Zones in Each Borehole Were Penetrated by Drilling |
|---|---|---|
| Checked by | Date | |
| Revisions | Date | |
| INTERA Technologies | | Table 5.1 |

## FLUID PROPERTIES FOR ALL BOREHOLES

| | |
|---|---|
| Fluid Compressibility | $3.1 \times 10^{-10}$/Pa ($2.1 \times 10^{-6}$/psig) |
| Fluid Density | 1200 kg/$m^3$ (74.8 lb/$ft^3$) |

## FORMATION PROPERTIES

BOREHOLE W782W

| | |
|---|---|
| Compressibility | $7.0 \times 10^{-11}$/Pa ($4.8 \times 10^{-7}$/psig) |
| Porosity | 0.25 |

BOREHOLES W805E and W805SW

| | |
|---|---|
| Compressibility | $1.9 \times 10^{-9}$/Pa ($6.9 \times 10^{-6}$/psig) |
| Porosity | 0.30 |

BOREHOLES W850W and W850SE

| | |
|---|---|
| Compressibility | $4.8 \times 10^{-11}$/Pa ($3.3 \times 10^{-7}$/psig) |
| Porosity | 0.02 |

BOREHOLE W1320E

| | |
|---|---|
| Compressibility | $2.5 \times 10^{-11}$/Pa ($1.7 \times 10^{-7}$/psig) |
| Porosity | 0.02 |

| | | |
|---|---|---|
| Drawn by | Date | Summary of Model Parameters for the Analysis of Tests in Boreholes in the Waste-Handling Shaft |
| Checked by | Date | |
| Revisions | Date | |
| INTERA Technologies | | Table 5.2 |

| BOREHOLE | LITHOLOGY | TEST ZONE | DEPTH INT. (Feet From Shaft Wall) | TEST PERIOD | PRESSURE PULSE (psig) | HYDRAULIC CONDUCTIVITY (m/s) | APPARENT FORMATION PRESSURE (psig) |
|---|---|---|---|---|---|---|---|
| W782W | Silty Mudstone | 1) | 18.6-26.0 | 07/18-22/87 | 113.3 | 1.0 E-13 | 90 |
| | | 2) | 12.3-15.9 | 07/20-22/87 | 108.3 | 1.0 E-14 | 140 |
| | | 3) | 5.4- 9.5 | 07/21-22/87 | 99.4 | 1.0 E-14 | 140 |
| W805E | Silty Claystone | 1) | 18.6-26.0 | 07/11-15/87 | 94.7 | 5.0 E-14 | 225 |
| | | 2) | 12.3-15.9 | 07/13-15/87 | 105.1 | 1.0 E-14 | 140 |
| | | 3) | 5.4- 9.5 | 07/14-15/87 | 97.8 | 1.0 E-14 | 110 |
| W805SW | Silty Claystone | 1) | 18.6-26.5 | 08/28-31/87 | 102.9 | 6.0 E-15 | 275 |
| | | 2) | 12.3-15.9 | Not Tested | | 1.0 E-14* | 90* |
| | | 3) | 5.4- 9.5 | 08/29-31/87 | 92.6 | 2.0 E-14 | 70 |
| W850W | Halite | 1) | 18.6-26.0 | 07-30/08-03/87 | 97.6 | 1.0 E-13 | 40 |
| | | 2) | 12.3-15.9 | 08/2-3/87 | 116.5 | 1.0 E-13 | 40 |
| | | 3) | 5.4- 9.5 | 07-31/08-3/87 | 90.4 | Not Analyzable | |
| W850SE | Halite | 1) | 23.2-36.0 | 08/19-24/87 | 103.5 | 3.0 E-14 | 50 |
| | | 2) | 16.8-20.5 | 08/21-24/87 | 103.1 | 3.0 E-14 | 45 |
| | | 3) | 10.0-14.1 | 08/22-24/87 | 100.7 | 2.0 E-14 | 90 |
| W1320E | Polyhalite/ Anhydrite/ Halite | 1) | 18.6-41.8 | 08/11-17/87 | 173.3 | 2.0 E-14 | 550 |
| | | 2) | 12.3-15.9 | 08/14-17/87 | 52.6 | 3.0 E-14 | 450 |
| | | 3) | 5.4- 9.5 | 08/15-17/87 | 53.0 | 3.0 E-14 | 100 |

*Zone #2 analysis from pressure buildup after shut in, August 28 to 31, 1987.

| Drawn by | Date | Summary of Hydraulic Conductivities and Formation Pressures Interpreted from the Testing of the Boreholes in the Waste-Handling Shaft |
|---|---|---|
| Checked by | Date | |
| Revisions | Date | |

INTERA Technologies

Table 5.3

# APPENDIX A

# DRILLERS LOGS

TABLE A.1

DRILLERS LOG FOR BOREHOLE W782E

| WIPP WASTE ISOLATION PILOT PLANT | TITLE: CORE DRILLING DATA<br>Location: W782 E Wall | Sandia National Laboratories LOG I.D. ____ PROCEDURE 92 REVISION 0 |
|---|---|---|

| DATE 7 / 31 / 87<br>SHIFT Swing | ROOM Shaft, waste<br>STATION 782<br>MINE COORDINATES ____ , ____ | HOLE NO. Z0X03 | TEAM DF,BS,SC,PH<br>APPROVAL BAS<br>Q. A. ____ |
|---|---|---|---|

DRILL SPECS Longyear D-65 HOLE DIA. 4 inches (in)
CORE BARREL SPECS 4" OD by 3' Diamond Masonary bit HOLE LENGTH 25 Ft 1 inch (ft)
DRILLING FLUID Air

HOLE LOCATION 782 Level EXACT ____ APPROXIMATE X

COLLAR : $X_1$(or R) ____ $Y_1$(or $\theta$) ____ $Z_1$ ____ (ft)
BOTTOM : $X_2$(or R) ____ $Y_2$(or $\theta$) ____ $Z_2$ ____ (ft)

HOLE COMPASS DIRECTION West to East ORIENTATION Horizontal @ 6° downward

| DATE | SEGMENT OR BOX NUMBER | CORE INTERVAL (DEPTHS) BEGINNING | CORE INTERVAL (DEPTHS) END | STORAGE LOCATION/ REMARKS |
|---|---|---|---|---|
| 7/27/87 | 7" core from | .0' | 1.0' | |
| | Liner | | | |
| 7/31/87 | Liner | 12 inches | 25 inches | 8:30 pm |
| | | | | |
| 7/31/87 | Z0X03/1 | 0.0' | 3.0' | |
| | Z0X03/2 | 3.0' | 6.0' | |
| | Z0X03/3 | 6.0' | 9.0' | |
| 7/31/87 | Z0X03/4 | 9.0' | 12.0' | Midnight |
| 8/1/87 | Z0X03/5 | 12.0' | 15.0' | |
| | | | | |
| | Z0X03/6 and 7 | 15.0' | 18.0' | 2 pieces |
| | | | | |
| | Z0X03/8,9,10 | 18.0' | 20.8' | 3 pieces |
| | | | | |
| 8/1/87 | Z0X03/11,12,13 | 20'10" | 22'11" | 3 pieces (2:05 AM) |

COMMENTS: core depths started with formation, Liner not counted.
This hole located on East Rib of Waste Shaft.



-OVER-

TABLE A.2

DRILLERS LOG FOR BOREHOLE W782W

| | | |
|---|---|---|
| WIPP<br>WASTE ISOLATION PILOT PLANT | TITLE: DRILLING LOG<br>**Location: W782 W Wall** | Sandia National Laboratories<br>PROCEDURE ______<br>REVISION 0 |

| | | | |
|---|---|---|---|
| DATE 7 / 15 / 87<br>SHIFT Swing | ROOM Shaft<br>STATION 782 | HOLE NO. Z0X02<br>GAGE NO. ______<br>GAGE TYPE ______ | TEAM DP,FP,PH,SC<br>APPROVAL BAS<br>Q. A. ______ |

| TIME | DEPTH | REMARKS |
|---|---|---|
| 8:30 | | Collar had been previously |
| | | installed. 7-7-87 |
| 8:30 - 11:00 | 26' pilot hole | 1-7/8 inch pilot hole drilled first. |
| | | |
| 11:00- 12:30 | 0' to 14' | 4" carbide bit with pilot. Wore |
| | | bit out pulled and replaced with 4" |
| 12:30-2:30 | 14' to 26' | drag bit without pilot |
| | | |
| | | |

| | $X_1(R_1)$ | $X_2(R_2)$ | $Y_1(\theta_1)$ | $Y_2(\theta_2)$ | $Z_1$ | $Z_2$ |
|---|---|---|---|---|---|---|
| SPECIFIED HOLE CORD. | | | | | | |

ACTUAL HOLE LENGTH 26' SPECIFIED DIA. 4" ACTUAL DIA. ______

DRILL RIG & BIT TYPE Diamec 230, 1-7/8 inch 3 wing carbide pilot bit, used 2-4 inch 3 wing carbide bits

NOTES:

1. SUBSCRIPT 1 SIGNIFIES BEGINNING OF HOLE & SUBSCRIPT 2 SIGNIFIES END OF HOLE

COMMENTS This hole was at the 782 level. Collar was grouted in. Hole was located on the west side of shaft, drilled at an angle of approximately 7 degrees downward. Drilled with Air as a circulation medium.

TABLE A.3

DRILLERS LOG FOR BOREHOLE W782SE

36

| WIPP WASTE ISOLATION PILOT PLANT | TITLE: DRILLING LOG Location: W782 SE Wall | Sandia National Laboratories PROCEDURE ______ REVISION 0 |
|---|---|---|

| DATE 8 / 1 / 87 SHIFT Swing | ROOM Waste Shaft STATION 782 | HOLE NO. Z0X01 GAGE NO. ______ GAGE TYPE ______ | TEAM BS,DP,PH,SC APPROVAL BAS Q. A. ______ |
|---|---|---|---|

| TIME | DEPTH | REMARKS |
|---|---|---|
| 6:00 - 6:30 | | Went through liner with 4" masonary bit |
| | | |
| 6:30 - 7:45 | 2' to 26' | Went to 26' from outside surface of |
| | | Liner with 1-7/8 inch carbide drag bit |
| 7:45 to 8:45 | 2' to 5' | Pulled 2 - 4" carbide drag bits |
| | | in 3 ft. Pulled off hole. |
| 8-3-87 | | |
| 9:00 PM | 5' to 8' | 4" core deviated from |
| | | pilot hole |

| | $X_1(R_1)$ | $X_2(R_2)$ | $Y_1(\theta_1)$ | $Y_2(\theta_2)$ | $Z_1$ | $Z_2$ |
|---|---|---|---|---|---|---|
| SPECIFIED HOLE CORD. | | | | | | |

ACTUAL HOLE LENGTH @ 8' SPECIFIED DIA. 4" ACTUAL DIA. 4"

DRILL RIG & BIT TYPE Longyear D-65 drill 1-7/8 3-way drag for pilot hole

NOTES:

1. SUBSCRIPT 1 SIGNIFIES BEGINNING OF HOLE & SUBSCRIPT 2 SIGNIFIES END OF HOLE

COMMENTS Because the formation dulled our 4" carbide bits we attempted to core with a 4" OD by 3 ft long diamond masonary bit but deviated from our pilot hole and drilling was suspended.

Location SE WAll

TABLE A.4

DRILLERS LOG FOR BOREHOLE W805E

| | | |
|---|---|---|
| WIPP<br>WASTE ISOLATION<br>PILOT PLANT | TITLE: DRILLING LOG<br>**Location: W805 E Wall** | Sandia National Laboratories<br>PROCEDURE ______<br>REVISION 0 |

30

| | | | |
|---|---|---|---|
| DATE 7 / 8 / 87<br>SHIFT Swing yard | ROOM Waste Shaft<br>STATION 805 | HOLE NO. Z0X06<br>GAGE NO. ______<br>GAGE TYPE ______ | TEAM DP-FP-SC-PH<br>APPROVAL BAS<br>Q. A. ______ |

| TIME | DEPTH | REMARKS |
|---|---|---|
| 7:00 | 18" | Pilot hole 1-7/8" Dia |
| 9:00 | 26' | |
| 9:15 | 18" | 4" Drag Bit |
| 1:00 | 26' | |
| | | |
| | | |
| | | |
| | | Set Collar 7-7-87 |
| | | Bret Stenson Personal Communication 9-9-87 |

| | $X_1(R_1)$ | $X_2(R_2)$ | $Y_1(\theta_1)$ | $Y_2(\theta_2)$ | $Z_1$ | $Z_2$ |
|---|---|---|---|---|---|---|
| SPECIFIED HOLE CORD. | | | | | | |

ACTUAL HOLE LENGTH 26' SPECIFIED DIA. 4" ACTUAL DIA. 4"

DRILL RIG & BIT TYPE Diamec 230 - 1-7/8" drag Bit - 4" Drag Bit w/pilot

NOTES:

1. SUBSCRIPT 1 SIGNIFIES BEGINNING OF HOLE & SUBSCRIPT 2 SIGNIFIES END OF HOLE

COMMENTS This hole was drilled with air as a circulation medium. A 1-7/8 inch pilot hole was drilled to 26 ft. and followed with a 4" 3 way carbide drag bit.

Holed drilled approximately 6° downward from Horizontal

TABLE A.5

DRILLERS LOG FOR BOREHOLE W805W

**WIPP**
**WASTE ISOLATION PILOT PLANT**

**TITLE: CORE DRILLING DATA**

**Location: W805 W Wall**

Sandia National Laboratories
LOG I.D. ____
PROCEDURE 92
REVISION 0

DATE 7 / 6 / 87
SHIFT 5:30 pm

ROOM Waste Shaft
STATION 805
MINE COORDINATES ____ , ____

HOLE NO. Z0X05

TEAM DP-PH-FP-SC
APPROVAL ____
Q. A. ____

DRILL SPECS Diamec 230 HOLE DIA. 4" (in)
CORE BARREL SPECS 4"x3' Masonary - 3-7/8 HOLE LENGTH 20'6" (ft)
DRILLING FLUID Air Rollercore

HOLE LOCATION EXACT ____ APPROXIMATE X

COLLAR : $X_1$(or R) ____ $Y_1$(or $\theta$) ____ $Z_1$ ____ (ft)
BOTTOM : $X_2$(or R) ____ $Y_2$(or $\theta$) ____ $Z_2$ ____ (ft)
HOLE COMPASS DIRECTION East to West ORIENTATION $6^{o}$ downward from horizontal

| DATE | SEGMENT OR BOX NUMBER | CORE INTERVAL (DEPTHS) BEGINNING | CORE INTERVAL (DEPTHS) END | STORAGE LOCATION/ REMARKS |
|---|---|---|---|---|
| 7-6-87 | #1 Run | 18" | 2.5' | Began Coring |
| | | 2.5' | 2.5' | |
| | | 3.5' | 5'2" | |
| | | 5.2" | 6.11" | |
| | | 6'11" | 9'8" | End Coring |
| Switched to Rollercone | | Drilled to | 20'6" | Crooked Hole |
| | | | | |
| | | | | |
| Set Collar 6-23-87 | Bret Stenson | Comminication 9/9/87 | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

COMMENTS: Collar Hole 7-1/2" - 18" Deep - 4" core to 9-8"
RollerCone to 20'6". Hole dropped off serverely using rollercone.



-OVER-

TABLE A.6

DRILLERS LOG FOR BOREHOLE W805SE

| WIPP WASTE ISOLATION PILOT PLANT | TITLE: DRILLING LOG<br>Location: W805 SE Wall | Sandia National Laboratories<br>PROCEDURE ______<br>REVISION 0 |
|---|---|---|

| DATE 6 / 23 / 87<br>SHIFT 3pm | ROOM Waste Shaft<br>STATION 805' | HOLE NO. Z0X04<br>GAGE NO. ______<br>GAGE TYPE ______ | TEAM DP-SL-FP-BS<br>APPROVAL BAS<br>Q. A. ______ |
|---|---|---|---|

Set Collar

| | TIME | DEPTH | REMARKS |
|---|---|---|---|
| 6-23-87 | | 0 to 18" | Collar Hole - Set Collar |
| 6-24-87 | | 18" to 14'3" | 4" Plug Bit |
| 6-25 | No access to shaft | | |
| 6-26 | Retrive Bit & Rod | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |

| | $X_1(R_1)$ | $X_2(R_2)$ | $Y_1(\theta_1)$ | $Y_2(\theta_2)$ | $Z_1$ | $Z_2$ |
|---|---|---|---|---|---|---|
| SPECIFIED HOLE CORD. | | | | | | |

ACTUAL HOLE LENGTH 14'3" SPECIFIED DIA. 4" ACTUAL DIA. ______

DRILL RIG & BIT TYPE Diamec 230 - 52" x 13-1/2" Masonary for Collar
4" Diamond Plug for Hole

NOTES:

1. SUBSCRIPT 1 SIGNIFIES BEGINNING OF HOLE & SUBSCRIPT 2 SIGNIFIES END OF HOLE

Grout
Randustrial F-190 Grout

COMMENTS
6-24 - Drilled to 14'3"
Lost Bit & 5' of rod.
6-25 No access to Shaft
6-26 - Retrieved Rod & Bit at 9:00 pm. Reentered Hole Lost Rod and Bit again. Retrieved Rod and Bit at 1:00 Am. Pulled out of 805' Level. Brine water for circulation.
This hole located on south side of shaft. This hole drilled approximately 6° downward from horizontal.

TABLE A.7

DRILLERS LOG FOR BOREHOLE W805SW

WIPP
WASTE ISOLATION PILOT PLANT

TITLE: CORE DRILLING DATA

Location: W805 SW Wall

Sandia National Laboratories — LOG I.D. ____ PROCEDURE 92 REVISION 0

DATE 8 / 22 / 87
SHIFT Swingyard

ROOM Waste Shaft
STATION 805
MINE COORDINATES ____ , ____

HOLE NO. Z0X11

TEAM FP,DP,PH,SC,
APPROVAL BAS
Q. A. ____

DRILL SPECS Diamec 230 Electrohydralic
HOLE DIA. 4 inch (in)
CORE BARREL SPECS 4" diamond masonary
HOLE LENGTH 26-1/2 feet (ft)
DRILLING FLUID Air and Water

HOLE LOCATION EXACT ____ APPROXIMATE X

COLLAR: $X_1$(or R) ____ $Y_1$(or $\theta$) ____ $Z_1$ ____ (ft)
BOTTOM: $X_2$(or R) ____ $Y_2$(or $\theta$) ____ $Z_2$ ____ (ft)

HOLE COMPASS DIRECTION North to South ORIENTATION 6° down from horizon

W 805 SW

| DATE | SEGMENT OR BOX NUMBER | CORE INTERVAL (DEPTHS) BEGINNING | CORE INTERVAL (DEPTHS) END | STORAGE LOCATION/ REMARKS |
|---|---|---|---|---|
| 8-22-87 | 1 | 0 | 3'2" | TIME 1930 |
| | 2 | 3'2" | 5' 10-1/2" | |
| | 3 | 5' 10-1/2" | 9' 1/2" | |
| | 4 | 9' 1/2" | 12' 1" | |
| | 5 | 12' 1" | 15'2" | |
| | 6 | 15' 2" | 19'2" | Last @ 1' of core |
| | 7 | 19' 2" | 22' 1/2" | |
| | 8 | 22' 1/2" | 24'2" | Time at 23-1/2 ft 233 |
| | | | | Stuck for two hours |
| | | | | until 0130 am |
| | | | | last 3 feet until 0230 |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

COMMENTS: Drilled through liner with water. Drilled to 23-1/2 feet with air. Drilled last 3 feet with brine.



-OVER-

TABLE A.8

DRILLERS LOG FOR BOREHOLE W850W

| WIPP WASTE ISOLATION PILOT PLANT | TITLE: DRILLING LOG<br>Location: W850 W Wall | Sandia National Laboratories<br>PROCEDURE ____<br>REVISION 0 |
|---|---|---|

| | | | |
|---|---|---|---|
| DATE 7 / 24 / 87<br>SHIFT Swing | ROOM Shaft<br>STATION 850 | HOLE NO. Z0X08<br>GAGE NO. ____<br>GAGE TYPE ____ | TEAM BS, RL, PH, SC<br>APPROVAL BAS<br>Q. A. ____ |

| | TIME | DEPTH | REMARKS |
|---|---|---|---|
| 7-22-87 | 10:30 - 2:30 am | 0' - 2' | cored 7" OD hole and set collar |
| | | | |
| 7-24-87 | 5:30 - 8:00 | 2' - 4' | core 4" hole through liner |
| | | | |
| | 8:00 - 10:00 | 4' to 25'6" | drilled 1 7/8 inch pilot hole |
| | | | with 3 way carbide drag bit |
| | | | |
| | 10:00 - 12:00 | 4' to 26' | drilled 4" hole with 3 way |
| | | | carbide drag bit. |

| | $X_1(R_1)$ | $X_2(R_2)$ | $Y_1(\theta_1)$ | $Y_2(\theta_2)$ | $Z_1$ | $Z_2$ |
|---|---|---|---|---|---|---|
| SPECIFIED HOLE CORD. | | | | | | |

ACTUAL HOLE LENGTH 26' SPECIFIED DIA. 4" ACTUAL DIA. 4"

DRILL RIG & BIT TYPE Diamec 230 electrohydralic 7" and 4" masonary
1 7/8 and 4.0 inch 3 way carbide drag bits

NOTES:

1. SUBSCRIPT 1 SIGNIFIES BEGINNING OF HOLE & SUBSCRIPT 2 SIGNIFIES END OF HOLE

COMMENTS Liner approximately 4 ft thick. We drilled through 3 pieces of 1 inch rebar. After penetrating liner we encountered water entering hole at a rate of one pint to one quart per minute estimated. This hole was located on the west side of shaft and Air was used as a circulation medium. This hole was drilled approximately 6° downward from horizontal.

TABLE A.9

DRILLERS LOG FOR BOREHOLE W850SE

| WIPP WASTE ISOLATION PILOT PLANT | TITLE: CORE DRILLING DATA<br>Location: W850 SE Wall | Sandia National Laboratories<br>LOG I.D. ____<br>PROCEDURE 92<br>REVISION 0 |
|---|---|---|

| | | | |
|---|---|---|---|
| DATE 8 / 3 / 87<br>SHIFT Swingyard | ROOM Waste Shaft<br>STATION 850<br>MINE COORDINATES ____ , ____ | HOLE NO. Z0X07 | TEAM DP,SC,PH,BS<br>APPROVAL BAS<br>Q. A. ____ |

DRILL SPECS Diamec 230 core drill HOLE DIA. 4 inches (in)
CORE BARREL SPECS 4 " OD diamond Masonary HOLE LENGTH 36 feet including Liner (ft)
DRILLING FLUID Air and Brine

HOLE LOCATION EXACT ____ APPROXIMATE X
COLLAR: $X_1$(or R) ____ $Y_1$(or $\theta$) ____ $Z_1$ ____ (ft)
BOTTOM: $X_2$(or R) ____ $Y_2$(or $\theta$) ____ $Z_2$ ____ (ft)
HOLE COMPASS DIRECTION North to South ORIENTATION 7° downward from horizontal

| DATE | SEGMENT OR BOX NUMBER | CORE INTERVAL (DEPTHS) | | STORAGE LOCATION/ REMARKS |
|---|---|---|---|---|
| | | BEGINNING | END | |
| 8-3-87 | Liner | 0" | 18" | Set Collar |
| | | | | TIME |
| 8-4-87 | Liner | 18" | 5'4" | Through Liner 1930 |
| | Formation | 0" | 6" | Plugbit No Core |
| 8-4-87 | 1 | 6" | 2'3" | Coring with Brine |
| | 2 | 2'3" | 4'10" | |
| | 3 | 4'10" | 7'1/2" | Drilling Rate |
| | 4 | 7'1/2" | 10'2" | Even, Slightly |
| | 5 | 10'2" | 13'3" | Faster at Shallow |
| | 6 | 13'3" | 16'5" | Depth Longer |
| | 7 | 16'5" | 19'4" | At Deeper Parts |
| | 8 | 19'4" | 22'3" | |
| | 9 | 22'6" | 25'7" | Lost @ 3"core |
| | 10 | 25'7" | 28'7" | |
| | 11 | 28'7" | 30'8" | TIME 0200 |

COMMENTS: Some leaching of core occured due to brine not being super saturated. Brine came from waste shaft sump.



-OVER-

TABLE A.10

DRILLERS LOG FOR BOREHOLE W1320E

| WIPP WASTE ISOLATION PILOT PLANT | TITLE: CORE DRILLING DATA<br>Location: W1320 E Wall | Sandia National Laboratories<br>LOG I.D. ____<br>PROCEDURE 92<br>REVISION 0 |
|---|---|---|

| | | | |
|---|---|---|---|
| DATE 8 / 7 / 87<br>SHIFT Swingyard | ROOM Waste Shaft<br>STATION 1320<br>MINE COORDINATES ____ , ____ | HOLE NO. Z0X10 | TEAM DP,SC,PH,BS<br>APPROVAL ____<br>Q. A. ____ |

DRILL SPECS Diamec 230 Electrohydralic HOLE DIA. 4 inches (in)
CORE BARREL SPECS 4" x3 ft Diamond Masonary HOLE LENGTH 42 (ft)
DRILLING FLUID Air

HOLE LOCATION 1320 Level EXACT ____ APPROXIMATE X
COLLAR : $X_1$(or R) ____ $Y_1$(or $\theta$) ____ $Z_1$ ____ (ft)
BOTTOM : $X_2$(or R) ____ $Y_2$(or $\theta$) ____ $Z_2$ ____ (ft)
HOLE COMPASS DIRECTION West to East ORIENTATION Horizontal $6^{o}$ down

| DATE | SEGMENT OR BOX NUMBER | CORE INTERVAL (DEPTHS) | | STORAGE LOCATION/ REMARKS |
|---|---|---|---|---|
| | | BEGINNING | END | |
| 8-7-87 | 1 | 0.0' | 3'2" | |
| 7:30 PM | 2 | 3'2" | 6'1-1/2" | |
| | 3 | 6'1-1/2" | 9'3-1/2" | |
| | 4 | 9'3-1/2" | 12'5" | Anhydrite in core |
| | 5 | 12'5" | 15'7-1/2" | start at 12 ft. |
| | 6 | 15'7-1/2" | 18'1-1/2" | |
| | 7 | 18'1-1/2" | 20'11-1/2" | |
| | 8 | 20' 11-1/2" | 24' 1-1/2" | |
| | 9 | 24' 1-1/2" | 27' 1-1/2" | |
| | 10 | 27' 1-1/2" | 29' 11" | |
| | 11 | 29' 11" | 32' 11-1/2" | |
| | 12 | 32' 11-1/2" | 35' 5" | |
| | 13 | 35' 5" | 37' 2-1/2" | |
| | 14 | 37' 2-1/2" | 39' 3-1/2" | |
| 8-8-87 2:30 AM | 15 | 39' 3-1/2" | 41' 10" | |

COMMENTS: Drilled with Air as circulation Medium. Went through Anhydrite starting at 12 ft and into polyhalite . Polyhalite to end of hole.



-OVER-

# APPENDIX B

# DRILLERS NOTES

DRILLING NOTES FROM TOM BURFORD, ASSISTANT DRILLER,
SANDIA NATIONAL LABORATORIES

WASTE SHAFT DRILLING

7-6-87

Set up on collar at 805' level.

1. Drilled 4" hole through liner. (diamond bit)

2. Used 4" barrel with cutrite through liner and approximately 4' into clay when forward movement ceased. Upon pulling cutrite barrel out noticed end had caved in - probably most of this was caused by forcing it through the liner and a slightly small hole. (Removed barrel)

3. Used 4" diamond end core barrel (got 9' of good core). Progressed to 9'8" into hole when forward progress was halted because:

   a) Circulation, air, had to be cut down because the air back pressure was pushing on the inside of the core barrel with enough force the drill could not force the barrel to advance.

   b) With circulation cut down a build up of cuttings around the bit caused some retrieval problems.

4. Pulled out of hole and decided to finish hole with rollercone assembly. This was delayed till 7/7 because R.C. not on gage. Had thought about possibility of using a smaller core barrel with cutrite on cutting edge to give a bigger space between barrel and hole. Also putting cutrite in intervals with spaces to give better circulation.

This idea was abandoned when I was informed that we did not have a back for a smaller diameter barrel.

5. Put in the third collar hole and grouted in the collar for 805.

7-7-87

1. Started with rollercone - went rather smoothly - some vibration occurred. Finished a 25' deep hole. Upon examination hole dipped severely at end and I felt until it was looked at by Wayne we would not risk doing another hole by rollercone until it was determined if it would be acceptable. I seriously doubt that it will be able to be used. Completed it at 9:45 PM.

2. Moved to the 782 level and drilled 2-1/2 collar holes and grouted in 2 collars.

TO DATE - 7-7-87 BITS USED AND STATUS

1. Plug bit - stuck using water for circulation

2. Carbide tip (cutrite) - while reaming through the 4" hole through liner bit collapsed.

3. Core barrel - worked ok but air circulation limited (bad) further into hole.

4. Rollercone - ok but inconsistent configuration would be good with stabilizer.

7-8-87

1. Set up to drill with drag bit - had Mike Carriaga fix an existing but damaged bit on Wednesday morning. Had 3 pilot bits and 1 drag bit with pilot and 1 drag bit on cage.

2. Started with 1-7/8" star type bit (pilot) went to 10' when chattering started and advancing slowed. Pulled bit found to be worn. Went back in with diamond plug bit finished 25' hole having to remove bit once to clean air ports.

3. Started with pilot led drag bit. Went to 15' when 6" pilot broke off bit. Retrieved pilot tube and finished 25'10" of the hole with the other drag bit. No other problems experienced and hole looked good.

4. After completion of hole spent 45 minutes in an effort to clean out all or as much of the cuttings as we could from this hole.

TDB

DRILLING NOTES FROM BRETT STENSON, CHIEF DRILLER, RE/SPEC, INC.

8-5-87

WASTE SHAFT DRILLING

782 Level

One hole was drilled to a depth of 26' by drilling a 1-7/8 inch pilot hole to the required depth and then following it with a 4" drag bit. Because of the abrasive nature of the formation 2 drag bits were worn out to complete the 26 foot hole. No water was encountered at this hole and this hole has been pressure tested.

A second hole was drilled at this level using a diamond masonry coring bit. Total hole depth was 25'1" from outside surface of liner. Approximately 23 feet of core was obtained. This hole has not been tested at this time.

A third hole was started using the same method as the first hole. A 1-7/8" pilot hole was drilled to 26' from outside surface of liner. Two drag bits were drilled in only 3 feet of drilling. This drilling took place on a Saturday 8-1-87.

We set up on this hole again the following Monday and attempted to core using 4" diamond core bit. Our set up was not accurate and when we pulled our first 3 foot core we found we were deviating from the pilot hole and drilling was stopped.

805 Level

This was the first level drilled. The first hole was drilled to 14'3". Drilling was being done with a 4" diamond plug bit using water as a circulation fluid. We lost the bit and rod down the hole twice and appeared to be wallowing the hole out badly and drilling on this hole was stopped.

The second hole on this level was drilled to a depth of 9'8" from inside surface of liner using a 4" masonry core bit. At this point the drill would not push the core barrel any further and we later discovered that we had a problem with the hydraulics on the drill. The hole was continued to a depth of 20'6" with a 3-7/8 inch rollercone but it curved down severely and drilling was stopped.

The third hole on the 805 level was drilled by punching a 1-7/8 inch pilot hole to 26 feet and following that hole with a 4" carbide drag bit. This method resulted in a good hole and this hole has been tested.

The first hole drilled on the 805 level to a depth of 14'3" is on the south side and it is producing water. It has been capped.

<u>850 Level</u>

The first hole drilled on the 850 level was on the west side. The liner was approximately 4' thick and we encountered several pieces of one inch rebar. A 1-7/8 inch pilot hole was drilled to 25'6" from outside surface of liner and followed with a 4" drag bit to a total hole depth of 26' from outside surface of liner. This was a good hole and it has been tested. This hole is producing water at a rate of approximately one quart per minute and it has been capped.

We are currently drilling the second hole on the 850 level on the south side. The liner on this side was 5'4" thick with rebar and the hole is producing water. We have obtained 8 feet of core from the formation and hope to go to approximately 40 feet tonight.

If all goes well we will begin coring on the 1320 level on Friday.

Recovered 30'8" of core last night for a total hole depth of approximately 37 feet. 30'8" total formation core from this hole will core at 1320 on Friday.

BAS

# APPENDIX C

# DETAILED CHRONOLOGY OF DRILLING AND TESTING

TABLE C.1

DETAILED TEST CHRONOLOGY FOR THE DRILLING AND TESTING OF BOREHOLE W782W

TABLE C.1
DETAILED TEST CHRONOLOGY FOR THE DRILLING AND TESTING OF BOREHOLE W782W

| DATE | TIME | ACTIVITY |
|---|---|---|
| 07-07-87 | | DRILLED THROUGH LINER AND SET COLLAR. LINER-FORMATION CONTACT APPROXIMATELY 33 INCHES FROM COLLAR. |
| 07-15-87 | 2030-2300 | DRILLED FROM 0 TO 26 FEET, PILOT HOLE WITH 1-7/8-INCH 3-WINGED DRAG BIT. |
| 07-15-87-07-16-87 | 2300-0030 | DRILLED FROM 0 TO 14 FEET WITH 4-INCH 3-WINGED DRAG BIT WITH PILOT BIT. |
| | | REPLACED WITH 4-INCH DRAG BIT WITHOUT PILOT. HOLE DRILLED APPROXIMATELY 7 DEGREES FROM HORIZONTAL. THE HOLE WAS DRILLED WITH COMPRESSED AIR. USED 2- TO 4-INCH 3-WINGED CARBIDE BITS. |
| 07-17-87 | 1830-2130 | INSTALLED MULTIPACKER TOOL INTO BOREHOLE W782W. |
| | 2230-2343 | FILLED BOREHOLE WITH 10-LB/GAL BRINE. |
| 07-18-87 | 0000 | BEGAN INFLATING PACKERS WITH FRESH WATER. PACKERS INFLATED TO 499 PSIG. |
| | 0030 | SHUT IN TEST ZONES. |
| | 1700 | INCREASED PACKER-INFLATION PRESSURE FROM 322 TO 517 PSIG. |
| | 1900 | INJECTED PRESSURE PULSE INTO ZONE #1: DURATION OF PULSE APPROXIMATELY 30 SECONDS, FLUID PRESSURE ROSE FROM 8 TO 122 PSIG. |
| 07-20-87 | 1830 | INCREASED PACKER-INFLATION PRESSURE FROM 474 TO 499 PSIG. |
| | 1930 | INJECTED PULSE INTO ZONE #2: DURATION OF PULSE APPROXIMATELY 50 SECONDS, FLUID PRESSURE ROSE FROM 69 TO 170 PSIG. |
| 07-21-87 | 1900 | INJECTED PRESSURE PULSE INTO ZONE #3: DURATION OF PULSE APPROXIMATELY 30 SECONDS, FLUID PRESSURE ROSE FROM 48 TO 147 PSIG. |

TABLE C.1 (continued)
DETAILED TEST CHRONOLOGY FOR THE DRILLING AND TESTING OF BOREHOLE W782W

| DATE | TIME | ACTIVITY |
|---|---|---|
| 07-22-87 | 1700 | SHUT DOWN DATA-ACQUISITION SYSTEM. |
| | 1830 | DEFLATED AND REMOVED TEST TOOL FROM W782W. |

TABLE C.2

DETAILED TEST CHRONOLOGY FOR THE DRILLING AND TESTING OF BOREHOLE W805E

TABLE C.2
DETAILED TEST CHRONOLOGY FOR THE DRILLING AND TESTING OF BOREHOLE W805E

| DATE | TIME | ACTIVITY |
|---|---|---|
| 07-07-87 | | DRILLED THROUGH LINER AND SET COLLAR. |
| 07-08-87 | 1900-2100 | DRILLED FROM 18 INCHES TO 26 FEET, PILOT HOLE WITH 1-7/8-INCH 3-WINGED DRAG BIT. |
| 07-08-87 | 2115-0100 | DRILLED FROM 18 INCHES TO 26 FEET WITH 4-INCH 3-WINGED DRAG BIT WITH PILOT. HOLE DRILLED APPROXIMATELY 6 DEGREES FROM HORIZONTAL. THE HOLE WAS DRILLED WITH AIR. |
| 07-10-87 | 1930 | INSTALLED MULTIPACKER TOOL INTO BOREHOLE W805E. |
| 07-11-87 | 0113-0125 | FILLED BOREHOLE WITH 10-LB/GAL BRINE. |
| | 0145 | ATTEMPTED TO ADD ADDITIONAL BRINE TO BOREHOLE. LITTLE OR NO ACCEPTANCE. |
| | 0200 | BEGAN INFLATING PACKERS WITH FRESH WATER. |
| | 0210 | SHUT IN TEST ZONES. |
| | 1800 | INCREASED PACKER-INFLATION PRESSURE FROM 354 TO 500 PSIG. |
| | 2001 | INJECTED PRESSURE PULSE INTO ZONE #1: DURATION OF PULSE APPROXIMATELY 30 SECONDS, FLUID PRESSURE ROSE FROM 130 TO 225 PSIG. |
| 07-13-87 | 1830 | INCREASED PACKER-INFLATION PRESSURE FROM 471 TO 495 PSIG. |
| | 1930 | INJECTED PRESSURE PULSE INTO ZONE #2: DURATION OF PULSE APPROXIMATELY 30 SECONDS, FLUID PRESSURE ROSE FROM 97 TO 202 PSIG. |
| 07-14-87 | 1830 | INJECTED PRESSURE PULSE INTO ZONE #3: DURATION OF PULSE APPROXIMATELY 30 SECONDS, FLUID PRESSURE ROSE FROM 93 TO 190 PSIG. |
| 07-15-87 | 1800 | SHUT DOWN DATA-ACQUISITION SYSTEM. |
| | 1830 | DEFLATED AND REMOVED TEST TOOL FROM W805E. |

TABLE C.3
DETAILED TEST CHRONOLOGY FOR THE DRILLING AND TESTING OF BOREHOLE W805SW

TABLE C.3
DETAILED TEST CHRONOLOGY FOR THE DRILLING AND TESTING OF BOREHOLE W805SW

| DATE | TIME | ACTIVITY |
|---|---|---|
| 08-22-87 | | SET COLLAR AND CORED THROUGH LINER WITH 4-INCH DIAMOND MASONRY BIT USING WATER. DRILLED TO 23.5 FEET WITH COMPRESSED AIR. DRILLED LAST 3 FEET WITH BRINE. HOLE DRILLED APPROXIMATELY 6 DEGREES FROM HORIZONTAL. |
| 08-26-87 | 1830-2100 | FILLED BOREHOLE WITH BRINE. |
| | | INSTALLED MULTIPACKER TOOL INTO BOREHOLE W805SW. |
| | 2235 | BEGAN INFLATING PACKERS WITH FRESH WATER. INFLATED PACKERS TO 518 PSIG. |
| 08-27-87 | 1525 | SHUT IN TEST ZONES. |
| 08-28-87 | 1800 | INJECTED PRESSURE PULSE INTO ZONE #1: DURATION OF PULSE APPROXIMATELY 150 SECONDS, FLUID PRESSURE ROSE FROM 49 TO 152 PSIG. |
| 08-29-87 | 1645 | INJECTED PRESSURE PULSE INTO ZONE #3: DURATION OF PULSE APPROXIMATELY 60 SECONDS, FLUID PRESSURE ROSE FROM 24 TO 117 PSIG. |
| 08-31-87 | 1130 | SHUT DOWN DATA-ACQUISITION SYSTEM. |
| | ~1830 | DEFLATED AND REMOVED TEST TOOL FROM W805SW. |

TABLE C.4

DETAILED TEST CHRONOLOGY FOR THE DRILLING AND TESTING OF BOREHOLE W850W

TABLE C.4
DETAILED TEST CHRONOLOGY FOR THE DRILLING AND TESTING OF BOREHOLE W850W

| DATE | TIME | ACTIVITY |
|---|---|---|
| 07-22-87 | 2230-0230 | CORED WITH 7-INCH MASONRY BIT FROM 0 TO 2 FEET AND SET COLLAR. |
| 07-24-87 | 1730-2000 | CORED THROUGH LINER WITH 4-INCH MASONRY BIT FROM 2 TO 4 FEET. |
| | 2000-2200 | DRILLED PILOT HOLE FROM 4 FEET TO 25 FEET 6 INCHES WITH 1-7/8-INCH HOLE 3-WINGED CARBIDE DRAG BIT. |
| | 2200-0000 | DRILLED FROM 4 TO 26 FEET WITH 4-INCH 3-WINGED CARBIDE DRAG BIT WITH PILOT BIT. BOREHOLE DRILLED APPROXIMATELY 6 DEGREES FROM HORIZONTAL. THE HOLE WAS DRILLED WITH COMPRESSED AIR. HOLE PRODUCING WATER FROM FRACTURE LOCATED APPROXIMATELY 65 INCHES IN FROM COLLAR. FRACTURE PRODUCES APPROXIMATELY 1 PINT PER MINUTE, POSSIBLY MORE. |
| 07-27-87 | 1800-2030 | INSTALLED MULTIPACKER TEST TOOL INTO BOREHOLE W850W. HOLE HAD ALREADY FILLED WITH FLUID ENTERING FROM FRACTURE OR SHAFT LINER-FORMATION CONTACT. |
| 07-28-87 | 0000 | BEGAN INFLATING PACKERS WITH FRESH WATER. |
| | 0030 | SHUT IN TEST ZONES. |
| | 1800 | INCREASED PACKER-INFLATION PRESSURE FROM 402 TO 494 PSIG. |
| 07-29-87 | 2100 | INCREASED PACKER-INFLATION PRESSURE FROM 437 TO 515 PSIG. |
| 07-30-87 | 0001 | INJECTED PRESSURE PULSE INTO ZONE #1: DURATION OF PULSE APPROXIMATELY 60 SECONDS, FLUID PRESSURE ROSE FROM 10 TO 108 PSIG. |
| 07-31-87 | 1630-1634 | INJECTED PULSE INTO ZONE #3: DURATION OF PULSE APPROXIMATELY 240 SECONDS, FLUID PRESSURE ROSE FROM 37 TO 54 PSIG. COULD NOT SUSTAIN A HIGHER PULSE INJECTION. |

TABLE C.4 (continued)
DETAILED TEST CHRONOLOGY FOR THE DRILLING AND TESTING OF BOREHOLE W850W

| DATE | TIME | ACTIVITY |
|---|---|---|
| 08-01-87 | 1335 | INCREASED PACKER-INFLATION PRESSURE FROM 459 TO 509 PSIG. |
| | 1530 | INJECTED PULSE INTO ZONE #2: DURATION OF PULSE APPROXIMATELY 30 SECONDS, FLUID PRESSURE ROSE FROM 18 TO 134 PSIG. |
| 08-03-87 | 0800 | SHUT DOWN DATA-ACQUISITION SYSTEM. |
| | 1800 | DEFLATED AND REMOVED TEST TOOL FROM W850W. |

TABLE C.5
DETAILED TEST CHRONOLOGY FOR THE DRILLING AND TESTING OF BOREHOLE W850SE

TABLE C.5
DETAILED TEST CHRONOLOGY FOR THE DRILLING AND TESTING OF BOREHOLE W850SE

| DATE | TIME | ACTIVITY |
|---|---|---|
| 08-03-87 | | CORED WITH 7-INCH DIAMOND MASONRY BIT FROM 0 TO 18 INCHES AND SET COLLAR. DRILLING THROUGH LINER. |
| 08-04-87 | | CORED WITH 4-INCH DIAMOND MASONRY BIT FROM 18 INCHES TO 5 FEET 4 INCHES THROUGH LINER. DRILLED WITH COMPRESSED AIR. |
| | | CORED WITH 4-INCH DIAMOND MASONRY BIT. DRILL BIT PLUGGED, NO CORE COLLECTED FROM 0 TO 6 INCHES. |
| | | CORED FROM 6 INCHES TO 30 FEET 8 INCHES USING BRINE. BRINE NOT SATURATED CAUSING SOME LEACHING OF CORE. BRINE CAME FROM WASTE SHAFT SUMP. |
| 08-18-87 | 1900-2100 | INSTALLED MULTIPACKER TOOL INTO BOREHOLE W850SE. |
| | 2300 | BEGAN INFLATING PACKERS WITH FRESH WATER. INFLATED PACKERS TO 500 PSIG. |
| 08-19-87 | 0002 | SHUT IN TEST ZONES. |
| | 2045 | INCREASED PACKER-INFLATION PRESSURE FROM 400 TO 521 PSIG. |
| | 2245 | INJECTED PRESSURE PULSE INTO ZONE #1: DURATION OF PULSE APPROXIMATELY 60 SECONDS, FLUID PRESSURE ROSE FROM 2 TO 105 PSIG. |
| 08-21-87 | 2030 | INJECTED PRESSURE PULSE INTO ZONE #2: DURATION OF PULSE APPROXIMATELY 20 SECONDS, FLUID PRESSURE ROSE FROM 10 TO 113 PSIG. |
| 08-22-87 | 1630 | INJECTED PULSE INTO ZONE #3: DURATION OF PULSE APPROXIMATELY 30 SECONDS, FLUID PRESSURE ROSE FROM 11 TO 111 PSIG. |
| 08-24-87 | 1830 | SHUT DOWN DATA-ACQUISITION SYSTEM. |
| | ~1845 | DEFLATED AND REMOVED TEST TOOL FROM W850SE. |

TABLE C.6

DETAILED TEST CHRONOLOGY FOR THE DRILLING AND TESTING OF BOREHOLE W1320E

TABLE C.6
DETAILED TEST CHRONOLOGY FOR THE DRILLING AND TESTING OF BOREHOLE W1320E

| DATE | TIME | ACTIVITY |
|---|---|---|
| 08-07-87-<br>08-08-87 | 1930-0230 | CORED FROM 0 TO 39 FEET 3.5 INCHES WITH 4-INCH BY 3-FOOT DIAMOND MASONRY CORE BARREL. DRILLED WITH AIR. HOLE DRILLED APPROXIMATELY 6 DEGREES FROM HORIZONTAL. |
| 08-08-87 | 1000-1230 | INSTALLED MULTIPACKER TOOL INTO BOREHOLE W1320E. |
| | 1336 | BEGAN FILLING BOREHOLE WITH 10-LB/GAL BRINE. |
| | 1440 | BEGAN INFLATING PACKERS WITH FRESH WATER. INFLATED PACKERS TO 518 PSIG. |
| | 1530 | SHUT IN TEST ZONES. |
| | 1800 | INCREASED PACKER-INFLATION PRESSURE FROM 402 TO 494 PSIG. |
| | 2000 | DAS SHUT DOWN |
| 08-10-87 | 1755 | DAS RESTARTED. |
| | 1840 | INCREASED PACKER-INFLATION PRESSURE FROM 437 TO 502 PSIG. |
| | 2036 | POWER FAILURE IN WHS DUE TO ELECTRICAL STORM, DAS SHUT DOWN. |
| 08-11-87 | 1800 | INJECTED PRESSURE PULSE INTO ZONE #1: DURATION OF PULSE APPROXIMATELY 60 SECONDS, FLUID PRESSURE ROSE FROM 74 TO 247 PSIG. |
| 08-12-87 | 1945 | INCREASED PACKER-INFLATION PRESSURE FROM 506 TO 605 PSIG. |
| | 2145 | INJECTED SECOND PRESSURE PULSE INTO ZONE #1: DURATION OF PULSE APPROXIMATELY 30 SECONDS, FLUID PRESSURE ROSE FROM 261 TO 311 PSIG. |
| 08-14-87 | 1815 | INJECTED PRESSURE PULSE INTO ZONE #2: DURATION OF PULSE APPROXIMATELY 30 SECONDS, FLUID PRESSURE ROSE FROM 311 TO 363 PSIG. |
| 08-15-87 | 1230 | INJECTED PRESSURE PULSE INTO ZONE #3: DURATION OF PULSE APPROXIMATELY 30 SECONDS, FLUID PRESSURE ROSE FROM 38 TO 91 PSIG. |

TABLE C.6 (continued)
DETAILED TEST CHRONOLOGY FOR THE DRILLING AND TESTING OF BOREHOLE W1320E

| DATE | TIME | ACTIVITY |
|---|---|---|
| 08-17-87 | 1815 | SHUT DOWN DATA-ACQUISITION SYSTEM. |
| | ~1845 | DEFLATED AND REMOVED TEST TOOL FROM W1320E. |

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