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Precision Pressure/Temperature Logging Tool

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Precision Pressure/Temperature Logging Tool

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Abstract

Past memory logging tools have provided excellent pressure/temperature data when used in a geothermal environment, and they are easier to maintain and deploy than tools requiring an electric wireline connection to the surface. However, they are deficient since the tool operator is unaware of downhole conditions that could require changes in the logging program. Tools that make "decisions" based on preprogrammed scenarios can partially overcome this difficulty, and a suite of such memory tools has been developed at Sandia National Laboratories. The first tool, which forms the basis for future instruments, measures pressure and temperature. Design considerations include a minimization of cost while insuring quality data, size compatibility with diamond-cored holes, operation in holes to 425°C (800°F), transportability by ordinary passenger air service, and ease of operation. This report documents the development and construction of the pressure/temperature tool. It includes: 1) description of the major components; 2) calibration; 3) typical logging scenario; 4) tool data examples; and 5) conclusions. The mechanical and electrical drawings, along with the tool's software, will be furnished upon request.

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Precision Pressure/Temperature Logging Tool

1 Introduction

Downhole temperature measurements are necessary for the evaluation of geothermal reservoirs, and they have been accomplished through the use of numerous devices. Simple measurements are made by using maximum-reading thermometers, or by using tabs constructed of temperature-sensitive materials that change color whenever a critical temperature is exceeded. Both devices return one data point per deployment, so a continuous log is not practical. The data from these devices may be in question because they respond to maximum temperature, and this may not be the bottom-hole temperature the user is assuming. Continuous logs from a single deployment are made by tools that return data to the surface through the use of an electric wireline, or from memory tools that store data either mechanically (by scribing a curve on a rotating cylinder) or electronically.

Continuous and repeated temperature measurements have been found to be much more desirable, especially when made at convenient times during a drilling operation, such as when the drill rig is receiving maintenance. The resulting data yields valuable information pertinent to the reservoir, and it helps in the design of the well itself. For example, even small lost-circulation zones produce a fine-structure on a temperature log, and these zones are candidates for future production since they exhibit above-average permeability. Furthermore, exercises involving the injection of cool fluids into the casing-formation annulus have been used to identify zones that possess an unsatisfactory cement bond.

Wireline tools and memory tools provide the user with the same quality measurement. Both systems have their advantages and disadvantages. The disadvantage of wireline tools is that they require the use of a logging truck and an electric cable which typically has a temperature limit of approximately 300°C (572°F). Logging trucks and high-temperature cable are expensive and require maintenance to ensure a quality log. The advantage is that the data is real-time, and as such, the tool functionality is known and unexpected situations can be overcome. The disadvantage of memory-based tools is that the tool's functionality is not known until the tool is retrieved and downloaded after the log. The advantage is that the tool can be deployed using a slickline which is inexpensive and is found at virtually all drilling operations. Therefore, no logging truck is required to deploy the tool.

Sandia National Laboratories, with funding from the U.S. Department of Energy, has developed geothermal logging tools based on the memory concept.[1] For a memory-based tool to be practical for use in the geothermal environment, it must possess some basic qualities: 1) the tool must be smart in the sense that it can be programmed to make "decisions"; 2) cost must be minimized within the constraint of satisfactory performance (an estimated component cost is listed in Appendix A); 3) the logging tool and ancillary equipment (with the exception of the cable assembly) must be transportable by ordinary passenger air service; 4) measurements must be traceable to national standards; 5) the tool should be compatible with diamond-core hole dimensions; 6) the tool must be operable to borehole temperatures of 425°C (800°F); 7) personnel training necessary for deployment and data retrieval should be minimal; and 8) the tool must be demonstrated to be rugged and reliable. The developed memory-based tools possess the above qualities.[2]

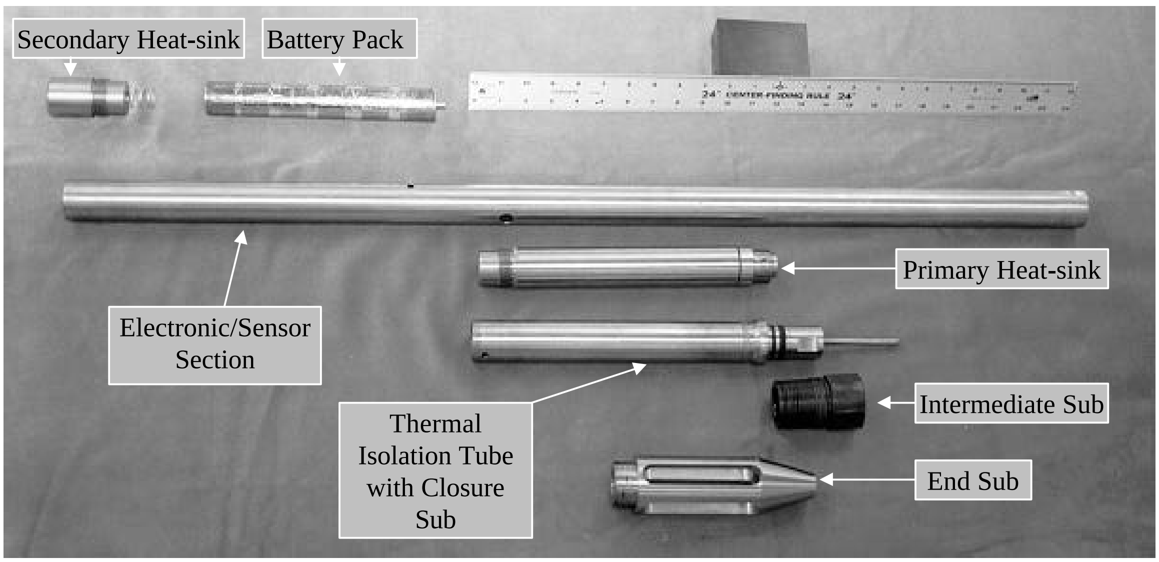


Figure 1. Major Temperature/Pressure Tool components.

2 System Components

The pressure/temperature tool is comprised of several subsystems. They consist of the following: 1) Dewar/pressure vessel; 2) electronics; 3) sensors; 4) power supplies; and 5) ancillary equipment.

2.1 Dewar/Pressure Vessel

The Dewar/pressure vessel utilized for this tool is manufactured by National K Works (Houston, TX). It is 1.84 meters (72 inches) long, has an outside diameter of 50 millimeters (2 inches), and has an inside diameter of 38 millimeters (1.5 inches). It is constructed using two concentric steel tubes. The outer tube constitutes the pressure housing, capable of withstanding up to 700 atm (10,000 PSI). A vacuum is established between the outer and inner tubes. This, along with proprietary materials, provides the thermal barrier needed to stand off ambient wellbore temperatures, protecting the Dewar's contents. The pressure seal is comprised of Viton o-rings (which make the initial pressure seal), and a metal-to-metal seal. This seal is needed for operations above 300°C where o-rings will fail. Sandia has considerable experience using this type of seal arrangement with excellent results. The outer tube is made of PH17-4 stainless steel. This material has a high yield strength and good corrosion-resistant properties. Other applications, such as long deployments in highly corrosive wells or applications requiring the use of a magnetometer, will require other alloys to be utilized. The inner tube does not have the strength or corrosion requirements of the outer tube. As such, it is made out of 300-series stainless steel. The sealing sub contains a thermowell (providing pressure protection for the temperature sensor) and a filtered pressure port.

Oven tests were performed to determine the length of time the pressure/temperature tool could safely be deployed in a geothermal well. Figure 2 depicts one of the oven tests. In this test the oven was preheated to 300°C (572°F). The tool was placed in the oven for approximately 3 hours. It was then taken out of the oven and allowed to air cool. The internal temperature increased approximately 20°C per hour during the test. In an actual geothermal static well log, the tool is typically not at a constant temperature because temperature varies with depth in the well. This normally would result in an internal temperature increase of less than 20°C per hour. A conservative estimate for the maximum time the tool could be deployed in a static geothermal well would be 6.5 hours, based on an initial internal temperature of 20°C and a maximum internal temperature of 150°C. Figure 3 represents an example of the Dewar's performance in a geothermal well.

The internal components of the Dewar/pressure vessel consist of the following: 1) isolation tube; 2) heat sink; 3) sensors; 4) electronics; and 5) batteries. The isolation tube is a thin-wall tube used to provide an air gap between the sealing sub and the heat sink. The heat sink is a thermal mass used to "absorb" the heat coming in from the sealing sub (a good portion of the heat transfer into the interior is from the sealing sub area). Details of the other components are covered below.

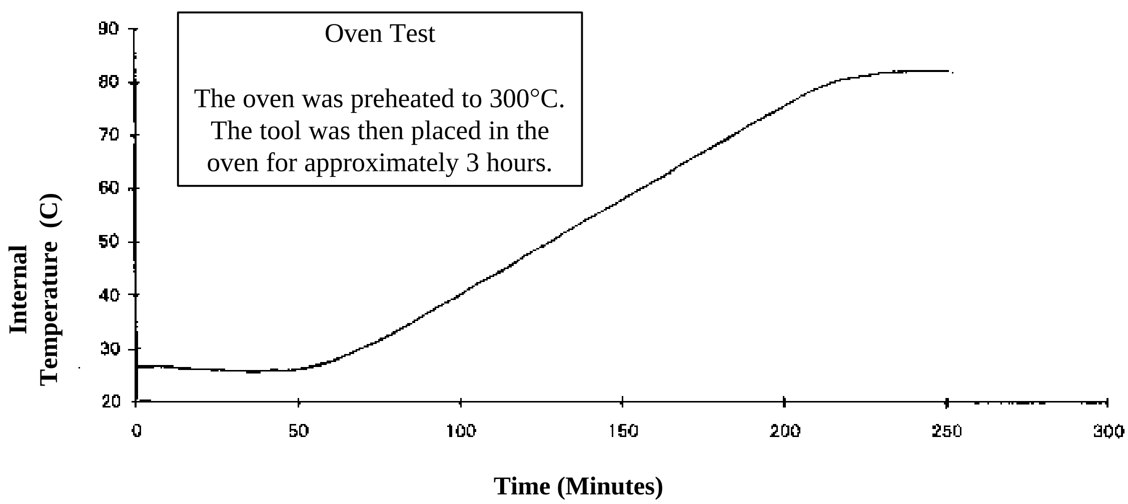


Figure 2. This graph indicates the Dewar's ability to insulate the electronics.

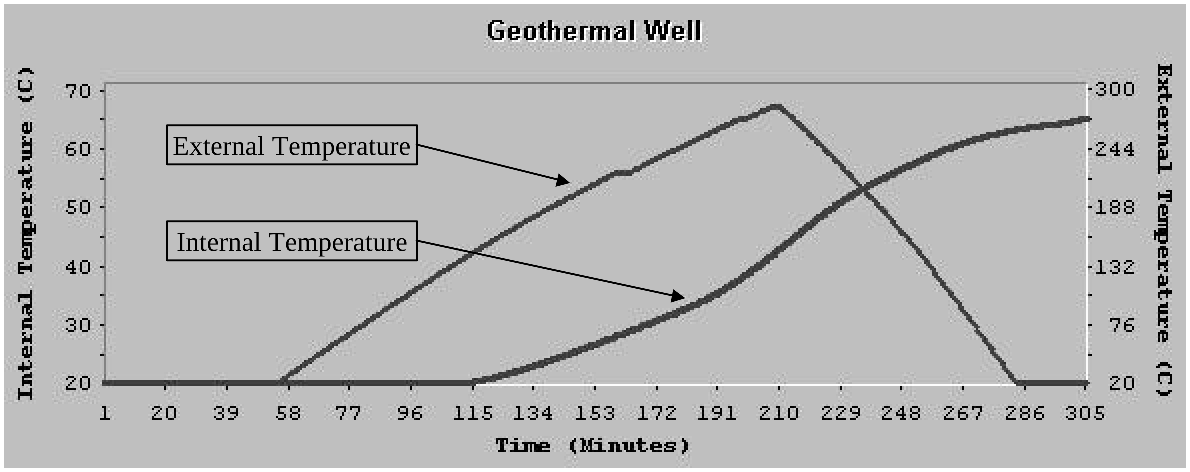
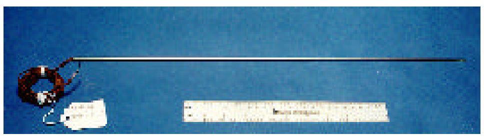


Figure 3. This graph represents the Dewar's behavior in a geothermal well.

2.2 Pressure/Temperature Sensors



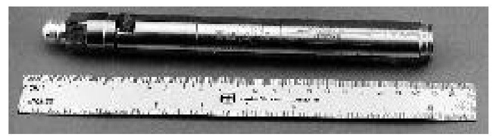


Figure 4. The photo on the left depicts the RTD temperature probe. It is 1/8 inch in diameter and 12 inches in length. The photo on the right depicts the pressure transducer. It is one inch in diameter and 9 inches in length.

Pressure measurements are needed to define the characteristics of a producing reservoir. Furthermore, pressure and temperature measurements provide a determination of depth assuming that the equation of state of the borehole fluid is known.[3] Measurement requirements are satisfied if pressure determinations can be made to ± 0.07 atm (± 1.0 psi). Quartz-oscillator transducers are capable of exceeding this requirement. Precision temperature measurements can be utilized to help characterize wells. Characteristics such as production zone, lost-circulation zones, change in lithology and steam-liquid interfaces can be ascertained from this measurement.

Presently, the tool utilizes the Quartzdyne, Inc, (Salt Lake City, UT) Model QB-10K quartz pressure transducer. By virtue of its design, it is well suited for use in a downhole application. It is robust for downhole applications and can handle air and truck shipments. It features a frequency output based on pressure, a frequency output based on the temperature of the transducer (this is used to maintain accurate pressure readings at elevated temperatures) and a reference frequency that can be used to determine the pressure frequency. Paroscientific, Inc. (Redmond, WA) Model 46K-178 pressure sensors were initially chosen for pressure measurements since they fit conveniently into the pressure vessel, and they were secondary standards used by the calibration teams at Sandia. While these sensors performed satisfactorily when used downhole, we found them sensitive to shock, and one unit was damaged in transit. Since the purchase of the Quartzdyne transducers, Paroscientific has developed a pressure transducer for downhole applications that is less shock-sensitive. Sandia has not tested this transducer.

Temperature measurements are made with an RDF Corporation (Hudson, NH) Model 218a(SP)-21-20-A-96 platinum Resistance Temperature Detector (RTD). Presently, the tool utilizes an Analog Devices part number AD7711 analog-to-digital converter to measure the resistance change of the RTD. It employs a sigma-delta conversion technique to realize up to 24 bits with no missing codes. This enables temperatures of ± .001°C to be resolved. It features a programmable-gain front end (which allows the use of different resistance-value RTD's without hardware changes), two-channel input (one differential analog input and one single-ended analog input), programmable digital filter, and access to the chip's on board calibration, all through a 3-wire serial interface. This device also features RTD excitation currents, but due to the temperature range the electronics will be exposed to, this option did not possess the temperature stability needed for this application. The excitation for the RTD is provided by an Analog Devices part number AD780 voltage reference. This device has excellent temperature stability.

The AD7711 has an operating temperature limit of 125° to 135°C (depending on the device tested). The device "shuts down" above this value until it is allowed to cool. The tool's microprocessor switches from the AD7711 to an Analog Devices voltage-to-frequency converter (AD537) to make the external temperature measurement when the tool electronics' internal temperature exceeds 115°C. An AD537 voltage-to-frequency converter was initially chosen for making this measurement in the prototype tool. The AD537 is operable above 150°C. It has an approximate 14-bit resolution capability (resolution of ± 0.008°C). After fielding this instrument, it was discovered that advanced temperature gradient measurements require a higher resolution than the AD537 could provide. This was not an original tool design criterion but would be useful in some geothermal applications.

2.3 Electronics

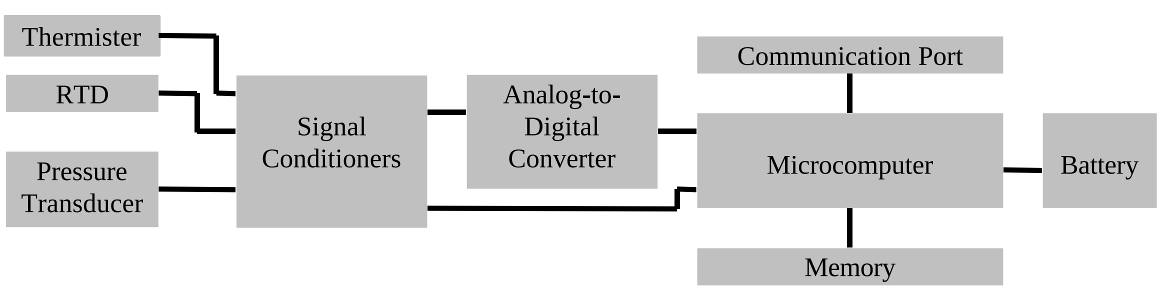


Figure 5. Block diagram of the tool's electronics.

The electronic package was designed to be the basis of present and future downhole memory-tool designs. It has several features built on the board that the temperature/pressure tool does not utilize. A summary of all its features includes: 1) simultaneously measures four frequencies; 2) two high-precision 24-bit analog-to-digital channels; 3) one medium-precision 14-bit voltage-to-frequency converter with a differential analog input instrumentation amplifier front end; 4) four 12-bit analog-to-digital channels; 5) battery backup for the data; 6) board temperature; 7) main battery voltage monitor; 8) two thermister inputs; 9) operation of an external relay; 10) seven I/O ports; and 11) tool status indicator.

The temperature/pressure tool is utilizing three of the frequency channels. Two channels are needed to make the pressure measurement (one for the pressure and the other for the temperature of the pressure transducer), and the third channel is needed to determine the frequency from the voltage-to-frequency converter AD537. The tool also utilizes a board-mounted, high-temperature lithium battery for memory back-up in the event the main batteries fail. A small light-emitting diode (LED) is used to provide the operator with an indication of tool status upon installation of the main batteries. The tool also monitors the board temperature and the battery voltage.

The heart of the electronic package is a microcomputer purchased from Onset Computing Company (North Falmouth, MA). Their Model 5F is of a size compatible with the 38-millimeter (1.5-inch) interior diameter of the pressure vessel. The microcomputer features one frequency (or period) port capable of measuring frequencies up to 30 KHz, eight 12-bit single-ended analog-to-digital input channels, fourteen I/O ports that can pass information to another computer or to switches, relays, and other devices such as the AD7711 used to make the external temperature measurement. It has 32 four-byte EEPROM storage locations that can be used to store sensor calibrations, serial numbers, etc. that would be unique to a particular tool. This memory has a finite number of write cycles. It has a 32K-by-8 flash EEPROM to store the operating system and the user’s program. It has one 512K-by-8 static RAM chip. This provides 480K bytes for data storage. The remaining memory is used to store the user’s program and the associated variables. While these features made the Model 5F suitable for this application, the system was not rated for operation at 150°C, the anticipated maximum operational temperature of the tool electronics. A series of oven tests, however, proved the system to be functional above this temperature. Qualifying components in excess of manufacturer’s specifications are common within the high-temperature electronics industry. The market is so small that almost no manufacturer tests above the military specification of 125°C. The Model 5F uses CMOS electronics and is a good candidate for high-temperature operation. Many CMOS devices have been qualified for operation up to 200°C.

The Model 5F requires some modifications to allow its use in this application. They include the following: 1) Battery backup capability. This feature is essential for a downhole tool. The RAM is backed up by a high-temperature battery that lasts for more than a year. This modification allows the data to be retained if the main battery fails. 2) Crystal-oscillator upgrade. Stable time is essential to allow the tool’s data to be properly synchronized with the uphole computer time and for accurate frequency-dependent measurements. A 9.8304 MHz crystal-oscillator from Hi-Temp Research Labs (Westlake Village, CA), Model C17TA, designed for use between 0 and 150°C (32 - 302°F) with a temperature stability of ± 50 PPM, is used by the microcomputer, the AD7711 analog-to-digital converter, and the field-programmable gate array (FPGA). 3) Modification to allow direct PC board mounting.

To allow the basic electronics board to be configured for future projects which may require additional or project-specific functions, the electronics board incorporates a field-programmable gate array (FPGA). This device is socket-mounted to allow it to be easily replaced. The FPGA is a one-time burn device that has a 512 logic gate capacity. The FPGA programmed for this application contains four 16-bit counters, four 24-bit counters, 24-bit four channel multiplexer, 24-bit parallel-to-serial converter, and various control-logic gates. Approximately 96% of the FPGA is being utilized. The counters allow four frequencies to be determined simultaneously. This is accomplished by: 1) resetting all counters simultaneously; 2) counting a predetermined number of pulses from the frequency to be measured by the 16-bit counters; 3) allowing the 24- bit counters to count the 9.8394 MHz reference frequency until the 16-bit counters are finished; and 4) reading the number of reference pulses that were counted for each of the frequencies. The predetermined number of pulses to be counted by the 16-bit counters is hardware-configurable. There are four options available. They are 4K, 8K, 16K, or 32K counts. This provides the user flexibility to customize the counters, depending on the application. The multiplexer, parallel-to-serial converter, and control-logic gates enable the counter information to be read by the microprocessor. Additional logic gates are programmed into the FPGA to communicate with the analog-to-digital converter and other I/O devices. The schematics of the FPGA are available upon request.

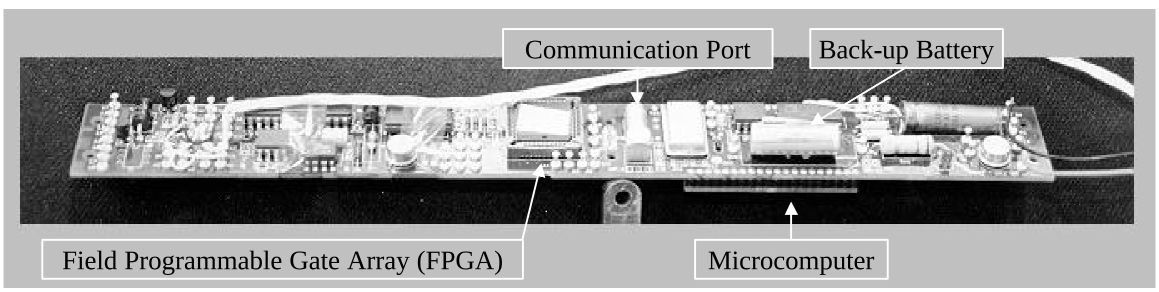


Figure 6. Electronic board (Board dimensions are 1.2 inches wide by 12 inches in length).

2.4 Power Supplies

A fifteen-volt, 40-milliampere power supply is required to drive the computing system, the pressure and temperature sensors, and ancillary components located on the circuit board during steady-state operating conditions. In addition, a short-duration current drain of several amperes may be needed to actuate devices such as a fluid sampling valve.

Ideally, the battery pack would be operable to the maximum temperature of other electronic components, low-cost and readily available, transportable by passenger air service, and would not produce hazardous waste. These requirements were found to be in conflict. Since the tool is intended for use in remote locations, perhaps outside the United States, the determining factor was deemed to be battery availability. Thus, the main power supply was constructed from five 2/3-A-size photo-flash cells (Duracell 123A). These cells are rated at 1,300 milliampere-hours, and they can deliver up to 4 amperes for a short duration. Unfortunately, they are rated to only 60°C (140°F). While laboratory experiments indicate that the cells are operable to at least 100°C (212°F), the tool should not be operated with these batteries where internal temperatures may exceed 60°C since the behavior of energetic devices containing corrosive chemicals is unpredictable.

Alternately, the tool can be supplied with high-temperature lithium/thionyl chloride cells available from Battery Engineering, Inc. (Hyde Park, MA). These cells cannot provide the higher currents, are not widely available, and are five times the price, but they will operate up to 150°C (302°F). Because of the chemistry needed to allow operation up to 150°C, they do not behave as predictably as standard batteries. An internal passivaton layer quickly forms during battery storage which seriously degrades battery performance. A procedure must be followed to de-passivate the batteries prior to deployment. This is not an insurmountable problem, but the user must be aware of this inherent characteristic. Recommendations for using high temperature batteries are documented in Appendix B.

In either case, the batteries are housed in a cylinder with spring-loaded contacts. Battery-pack assembly recommendations are given in Appendix C.

2.5 Ancillary Equipment

Ancillary equipment required to perform a log with the pressure/temperature tool consists of a means to record depth and an IBM-compatible computer running Microsoft Windows 3.1. Depth recording is accomplished by an encoder attached to wheels of known circumference. The wheels rotate as the logging cable is moved. The encoder converts the direction and rotation to electronic pulses. The encoder is normally mounted on the logging truck or slickline trailer. Necessary support electronics, including depth and velocity displays manufactured by Red Lion Controls (York, Pa), are contained in a box that is air-transportable. This box is referred to as the depth-display system. The same IBM-compatible computer used to operate the tool is normally used to record the depth and line velocity.

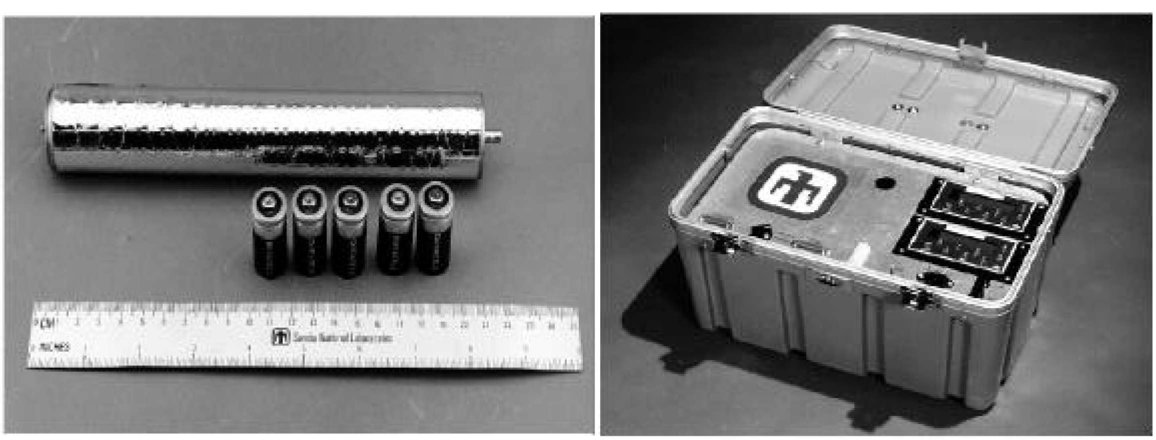


Figure 7. The photo on the left depicts the tool's battery pack and batteries while the photo on the right depicts the Depth-Display System.

3 System Calibration

Prior to system calibration, the electronic board is “burned-in” to identify any components that may fail prematurely. This is accomplished by operating the electronics while performing a minimum of three cycles through the expected internal temperature range inside the Dewar. This temperature range is 0 to 150°C (32 - 302°F). The electronics are held at 150°C (302°F) for a minimum of seven hours at the completion of each cycle.

To establish the measurement variation the electronics will have due to increasing board temperature inside the Dewar, the electronics are placed in an oven with the pressure transducer. Borehole temperatures are simulated through inputs from a calibrated resistance box outside the oven. Likewise, pressure is imposed on the pressure transducer with a calibrated dead-weight test device. Ten predetermined resistance values and pressures were imposed on the electronics at six temperatures between 0 and 150°C (32 - 302°F). The variation due to temperature is recorded and, if needed, can then be compensated. In testing, the AD7711 required no compensation. The pressure transducer has a temperature sensor built into the unit to compensate for temperature variations that would affect the pressure measurement. The manufacturer’s coefficients were verified, and no further compensation was required. The AD537, however, does need to be compensated. The oven temperature is monitored using a calibrated thermometer. Oven temperatures are used to calibrate the board-mounted thermister that provides the internal-temperature measurement.

The final step in the calibration process is to incorporate into the system the RTD that will be used to make the external temperature measurement. This is done by connecting the RTD to the electronics using the proper length of wire to enable its use in the assembled tool. The RTD is placed in an RTD heat source. This device has an aluminum block with several holes. The RTD to be calibrated is placed into this block along with a primary-standards-quality reference probe. Ten temperature values between ambient and 400°C (752°F) are used to formulate the coefficients needed to calibrate the tool’s RTD. Using the generated data, a scientific plotting and data analysis software package from Spiral Software is utilized to generate a third-order polynomial equation. The tool’s software calculates the temperature using this equation. A probe calibrated to primary-standards relies on known melting and freezing points of different materials. These values are known to a very high degree of accuracy. The reference probe can then be calibrated to a high degree of accuracy. It is standard practice for temperature measurements to reduce the claimed accuracy of a probe that is calibrated using another probe for reference by a factor of 10 for a calibration interval of one year. The higher the accuracy of the reference probe, the higher the secondary probe’s claimed accuracy can be. The reference probe used to calibrate the RTD has an accuracy of ± 0.02°C for temperatures up to 100°C and ± 0.05°C for temperatures between 101° and 400°C. Therefore, the tool’s RTD, when it is calibrated as a system, can have a claimed accuracy of ± 0.2°C for temperatures up to 100°C and ± 0.5°C for temperatures between 101° and 400°C. Calibration is verified to be correct by heating the probe in the RTD heat source to values not used to determine the calibration coefficients. An example of the curve associated with the RTD's calibration and the curve-fit equation is shown in figure 8.

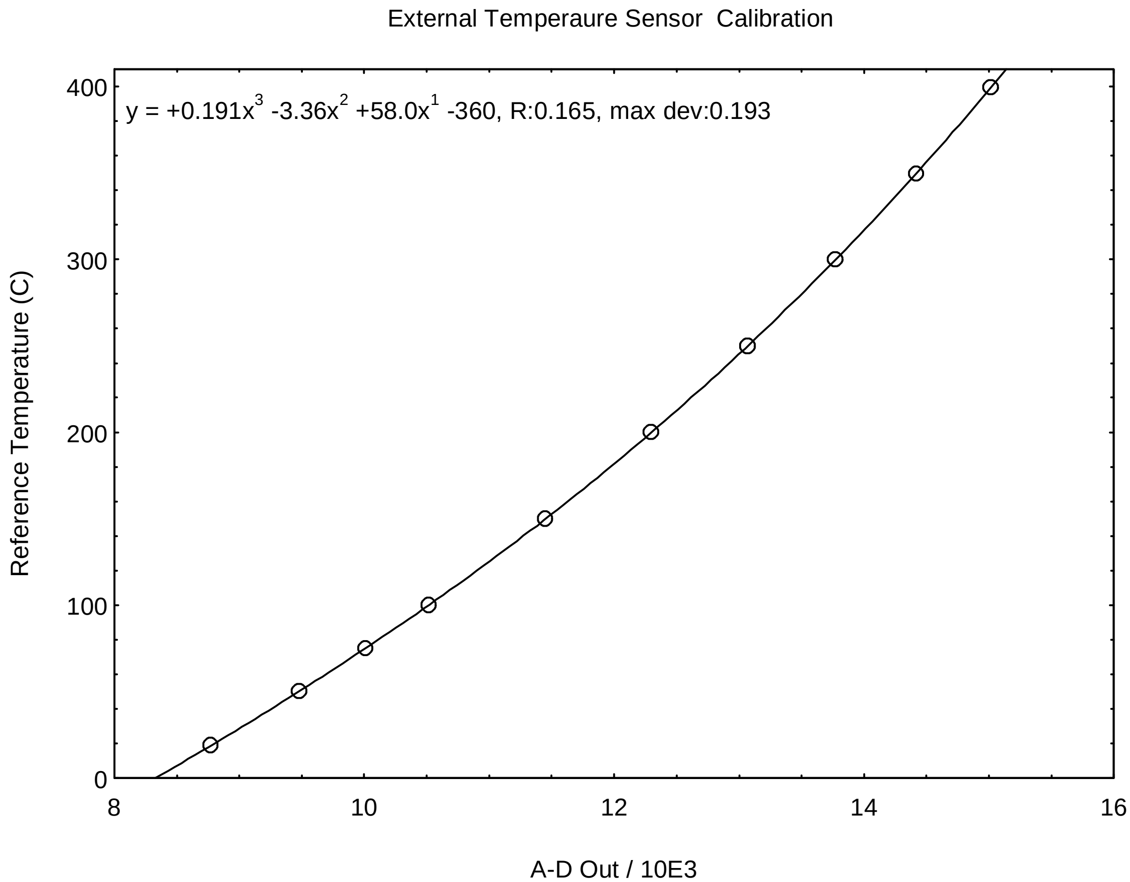


Figure 8. A graph showing an example of the external- temperature calibration equation.

4 Software

Software to deploy the tool consists of the following: 1) tool software that controls the operation of the tool downhole; 2) a Windows-based program that synchronizes the computer time with the tool time and establishes the run-time parameters for the tool, records the depth information, and performs the data offloading of the tool data; 3) a Windows-based program to merge the data-time and depth-time information to obtain data-depth information; and 4) a Windows-based program to display the data.

5 Logging Scenario

While there are many factors that may influence the set-up and operation of the pressure/temperature tool, the following is an example of the steps required to operate the tool:

5.1 Before Log

1) Prepare the battery pack for deployment. Details on the battery pack assembly are documented in Appendix C.
2) Purge the pressure transducer line. This is accomplished by removing the outer sleeve from the primary heat-sink to expose the purge fitting. Remove this fitting and install the oil can adapter fitting. Inject oil into this line until no bubbles are present at the pressure inlet port (the tool's end sub should be slightly elevated). Replace the purge fitting and re-install the outer sleeve to the primary heat-sink.
3) Connect the encoder to the wireline or slickline that will be used to lower the tool into the well. Verify depth calibration with the wireline/slickline operator. Note: Calibration may require the scale factor for the depth display system to be adjusted.
4) Install the battery pack and replace the secondary heat-sink.
5) Connect the tool to a laptop computer.
6) Click on the PT Tool software icon. Press the "tool start" button. This Windows-based program will step the user through the tool set-up procedure. This includes synchronizing the computer time with the tool time and establishing the run-time parameters for the tool.
7) After the tool is started and the light-emitting-diode (LED) indicator is illuminating at every data interval, disconnect the tool from the computer.
8) Assemble the tool. This is accomplished by: a) Attaching the appropriate tool top adapter to the top of the Dewar to enable connection to the slickline/wireline. b) Sliding the tool into the Dewar and attaching the proper end sub. Note: The tool is kept from rotating when the end sub is screwed into place by utilizing the end sub wrench. This wrench has pins that engage into the tool's pressure sub and is held while the end sub is screwed into place. c) Installing the Belleville washers along with the brass load washer. d) Attaching the bull nose that protects the thermal well and has a tapered bottom end. Note: The Dewar is prevented from rotating using a girth wrench placed approximately 6 inches from the end of the Dewar's opened end.
9) Connect the assembled tool to the slickline/wireline.
10) Connect the depth display system to the computer. Press the "record depth" button. This part of the program steps the user though the process required to record the depth information. Recording of the depth information dominates the computer for the duration of the logging process. When the time is appropriate, initiate the start of the depth file by clicking on the "start test' button. The user can set flags which are indicated in the depth file as a flag number with a time stamp. This feature is useful to later identify logging activities that may have transpired during the log (such as the tool "hanging up" in the well). Note: The laptop computer used to take the depth information must have the power- and screen-saving options turned off.

5.2 After Log

1) Disconnect the tool from the slickline/wireline.
2) Stop the computer from taking depth information by clicking on the “end test” button. Enter any post-log comments. The program will display the main menu.
3) Disassemble the tool and remove the electronics from the Dewar.
4) Connect the communication port to the computer and click the “offload tool” button from the main menu. The program will prompt the user for the file name to use to store the tool’s data. Click the “offload” button to initiate the offload. The program will display the status of the offload process and will display the main menu when the offload is complete. Click the “exit” button to terminate this program.
5) Click the “merge” icon. This will initiate the merging of the data vs. time file from the tool with the depth vs. time from the depth file to create the depth vs. data file. The program will prompt the user for the two files to merge and the name of the file that will contain the merged data. As the files are being merged, the program will display the maximum temperature of the well for the user’s convenience. When this process is complete, select “file” and then “exit” to terminate this program.
6) Now the data is ready for displaying. This is accomplished by clicking on the “display” icon. This program will display the data vs. time or depth. The user can select what data to display by choosing a variety of predefined buttons. The user can display two sets of data on one plot. Buttons can be added or edited to better display data for a particular application. The data can be filtered, if needed, by setting up the filter option in this software. This program has several unique features to enable the tool’s data to be displayed and printed easily. Alternately, the data can be imported into other programs such as Lotus or Excel for plotting.

6 Tool Data Examples

The following graphs are examples of the type of data one can expect from the presssure/temperature tool.[4]

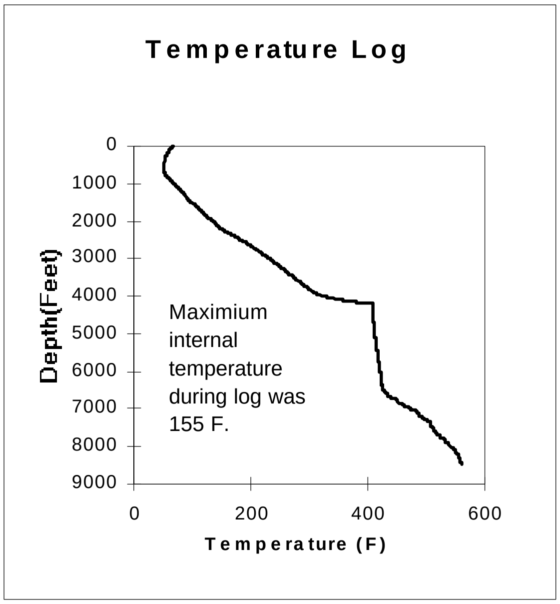


Figure 9. An example of the temperature data.

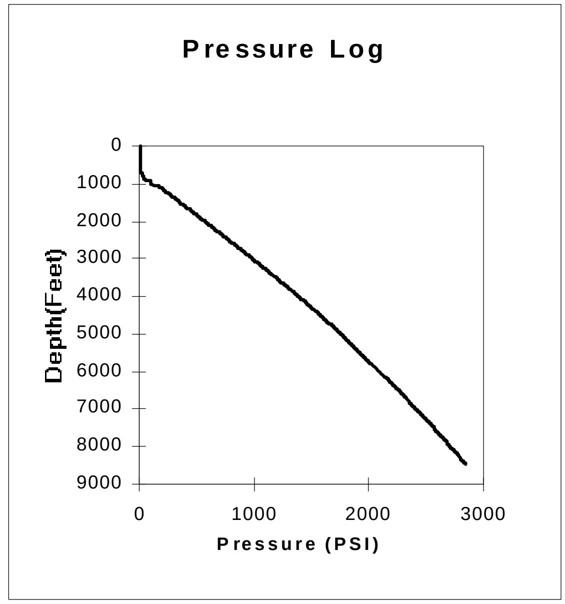


Figure 10. An example of the pressure data.

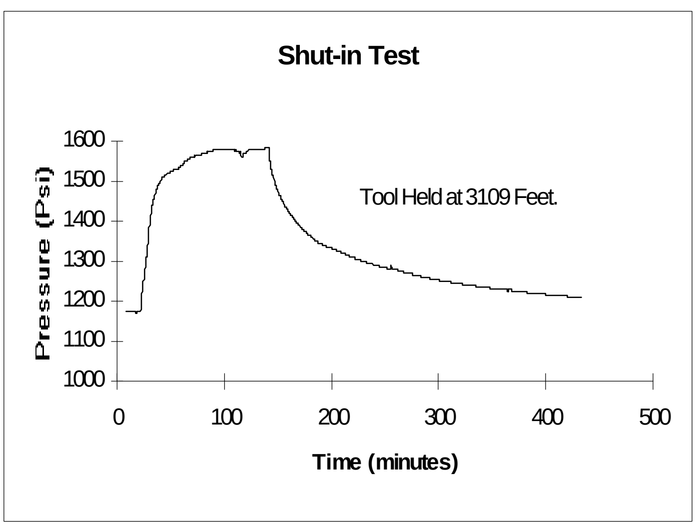


Figure 11.. An example of the tool being utilized during a shut-in test to help determine wellbore permeability.

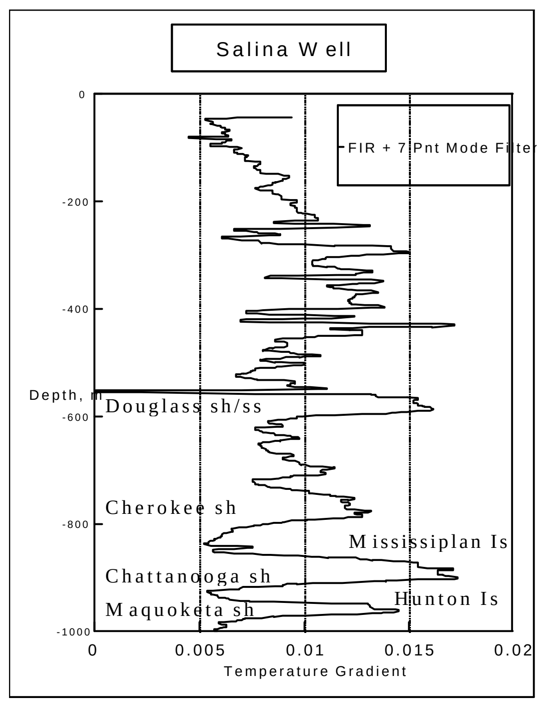


Figure 12. An example showing how temperature-gradient tool data can be utilized to help map changing lithology in the well.

7 Conclusion

This tool was designed to provide the geothermal industry with a reliable, easily transportable, precision pressure/temperature tool with design attributes that minimize cost. It has been utilized in the harsh geothermal environment to perform several dozen logs without a single failure or loss of data. Software to deploy the tool is Windows-based and has been developed to be easy to implement. The tool is easily transportable. The tool and its associated components have been checked as “baggage” on many airline flights and flown to job sites.

The mechanical and electrical drawings along with the tool’s software will be furnished upon request.

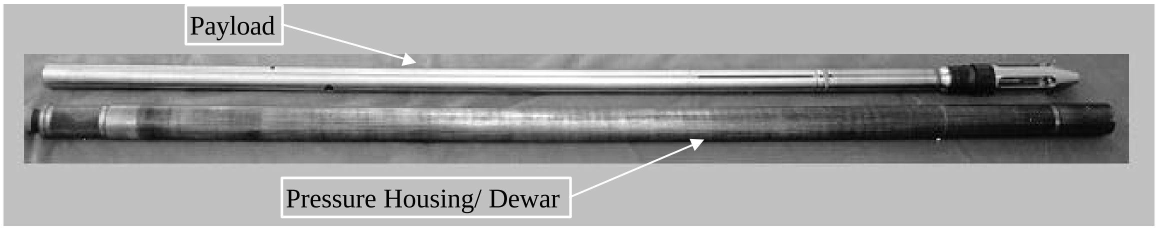


Figure 13. Pictured above is the Pressure/Temperature Tool. The tool is approximately six feet in length.

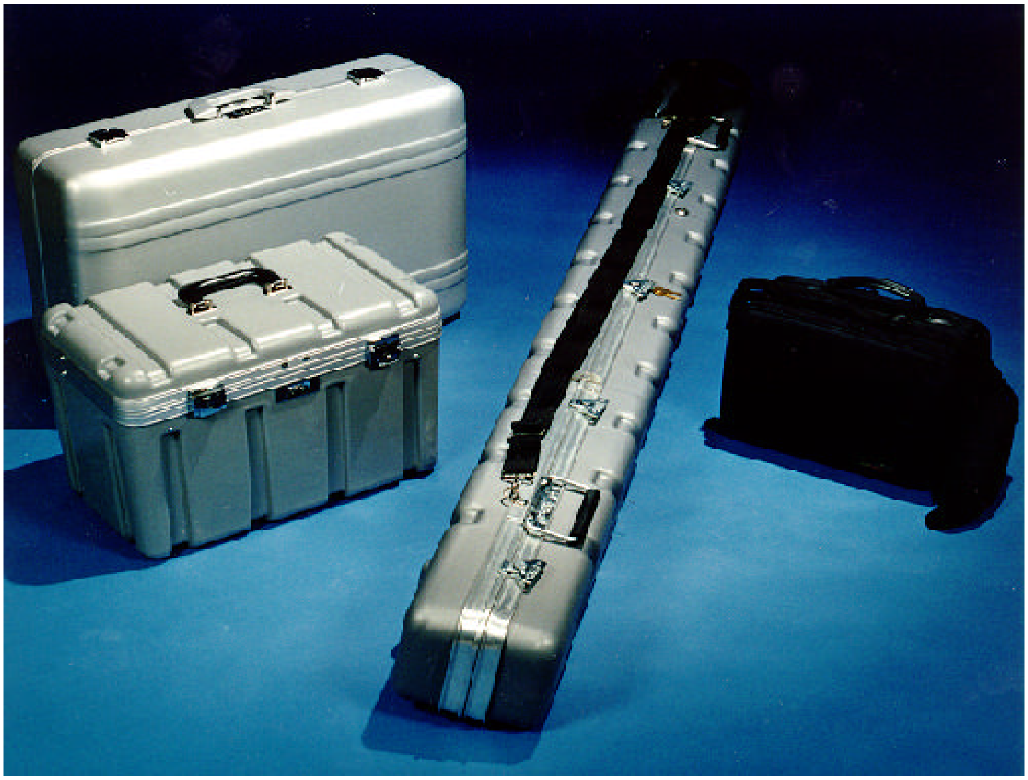


Figure 14. Pictured above is the Pressure/Temperature Tool and its associated components ready for air transportation to the well site.

8 References

1. Lysne, P., R. Normann, and J. Henfling, “Instrumentation Development in Support of the Geothermal Industry”, *Federal Geothermal Research Program Update 1995*, U.S. Department of Energy, pp.3-23 through 3-28, 1995.

2. Lysne, P.,and J. Henfling, “Design of a Pressure/Temperature Logging System for Geothermal Applications”, *Proc. U.S. Dept. of Energy Geothermal Program Review XII*, pp.155-161, 1994.

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4. Normann, R., J. Henfling, and D. Blackwell, “Development and Field Use of a Memory-Based Pressure/Temperature Logging Tool for the Geothermal Industry”, *Proc. U.S. Dept. of Energy Geothermal Program Review XIV*, pp. 255-260, 1996.

Appendix A

Component Cost Estimate for the Pressure/Temperature Logging System

The total component cost of the pressure/temperature logging system (excluding the IBM-compatible computer and Microsoft Windows operating system, is estimated to be $17,700. The cost is summarized in Table 1. These costs reflect the component parts, and they do not take into account engineering overhead and any profit that a service company would require if it is to undertake support of the tool.

Pressure transducer	$ 5600
External temperature sensor (RTD)	100
Electronics board	1500
Internal hardware	500
Dewar/Pressure housing	9000
Depth-Display System	1000
Totals	$17,700

Table 1. Estimate of the component cost.

Appendix B

Recommendations on High-Temperature Battery Use

Before the high-temperature batteries from Battery Engineering can be utilized, a test to determine the presence of a passivation layer must be performed. The following steps must be taken:

1) Place the battery pack into the battery carrier.
2) Connect a 1300-ohm load connector to the battery carrier and monitor the voltage.
3) If the voltage does not drop to less than 16.5 volts, proceed to step 4. If the voltage does drop to less than 16.5 volts, there is a passivation layer. The load must remain connected until the voltage is greater than 16.5 volts. This may take up to 72 hours.
4) Connect a 500-ohm load and monitor the voltage for 15 minutes. The voltage should not drop below 14 volts. If it does, do not use the battery pack.
5) Disconnect the load. The battery pack is ready for service.

High-temperature batteries have a reduced current capability and capacity at room temperature. The time it takes to depassivate the battery pack in step three of the above procedure could be reduced by heating the battery pack to 40°C. Better battery performance is realized if the battery pack is preheated to 40°C prior to deployment.

Appendix C

Battery-Pack Assembly Recommendations

Commercially available photo-flash batteries (Duracell 123A)* and high-temperature batteries from Battery Engineering can be utilized in the battery pack carrier. The following is a description of the technique used to assemble a battery pack:

The photo-flash batteries are prepared by cutting a length of shrink tubing slightly shorter than the length of five cells. The shrink tubing is pre-shrunk to a diameter slightly larger than the batteries. This is done by placing the shrink tubing on a pre-heated mandrel (a heat gun is used as the heat source). While the tubing is warm, remove the shrink tubing, from the mandrel. The batteries are installed in series inside the prepared shrink tubing and the batteries are held together as the shrink tubing is shrunk to its final size. The batteries are now ready for installation into the battery carrier housing.

The high-temperature batteries are larger in diameter and shorter in length. A metal sleeve is removed from the battery-carrier housing to allow for this larger diameter. An aluminum spacer is used in conjunction with the battery pack to accommodate the shorter length. The battery is available in a “button cap” arrangement allowing for similar battery pack assembly as with the photo-flash batteries.

***Warning: Sandia, has used the Duracell 123A batteries successfully on the majority of well logs. In each case we understood the hazard and took precautions. In NO logging tests did we expose the batteries to temperatures greater than 85°C (oven tests were performed to 100°C). Use these batteries at your own risk.**

Appendix D

Summary of the Pressure/Temperature Tool Specifications

Physical:

2 inch O.D.
72 inch length
1.25 - 8 threaded tool top (with an adapter to ¾ - 16 thread)
Temperature rating—up to 425°C
Pressure rating—up to 10,000 PSI

Electronics:

Microcomputer—HD6301
Program memory—32K Flash EEPROM
Data memory—480K Static RAM with battery back-up
Data points—greater than 12000
Crystal frequency—9.8304 MHZ
Crystal stability—± 50 PPM from 0 to 150°C

Sensors:

Pressure transducer type—Quartz, with quartz resonator temperature sensor to provide digital thermal compensation over the calibrated range of 0 to 150°C.
Pressure range—to 8000 psi
Accuracy— ± 0.02% F.S.
Repeatability—± 0.01% F.S.
Resolution—0.01 psi

Temperature sensor type—Platinum RTD
Calibrated temperature range—ambient to 400°C
Accuracy—± 0.2°C (ambient to 100 °C) and ±0.5°C (101 to 400°C)
Resolution—0.001°C

Power Supply:

Voltage—12 - 15 D.C.
Current—0.040 amps
Operates on standard "photo flash" batteries, 2/3-A-size, (5 each required, available from Duracell) or high temperature (150°C temperature rating) 2/3-C-size cells (5 each required, available from Battery Engineering, Inc.).

Additional features:

Internal-temperature monitor
Battery-voltage monitor
Tool-status indicator

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