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MASTER
Development of an Instrument to
Measure the Concentration of
Noncondensable Gases in
Geothermal Discharges

FINAL REPORT

C. K. Blair and R. F. Harrison
Terra Tek, Inc.

January 1980

**Geothermal
Reservoir
Engineering
Management
Program**

Earth Sciences Division
Lawrence Berkeley Laboratory
University of California

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DEVELOPMENT OF AN INSTRUMENT TO
MEASURE THE CONCENTRATION OF NONCONDENSABLE
GASES IN GEOTHERMAL DISCHARGES, 3rd Edition

FINAL REPORT

Project Duration: October 1, 1978 - September 30, 1979

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DEVELOPMENT OF AN INSTRUMENT TO MEASURE THE CONCENTRATION OF NONCONDENSABLE GASES IN GEOTHERMAL DISCHARGES

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ABSTRACT

Reported herein is a summary of a project to design, construct, and test a device which will continuously measure the vapor phase concentration of noncondensable gases in saturated steam/water geothermal discharges. Descriptions of the design, operating procedures, measurement accuracy, and limitations of the device are included. Also presented are results of laboratory testing and of field demonstration of the instrument. Recommendations for further refinement and development of the apparatus are discussed.

PROJECT SUMMARY

This project was a one year program to develop an instrument having the capability of continuously measuring the concentration of noncondensable gases in the vapor phase of saturated steam/water geothermal discharges. During the course of the project, the engineering design of the instrument was completed, two devices were fabricated, laboratory testing of one device was conducted, and field testing of both units was performed at geothermal sites in the United States and in New Zealand.

Monitoring the level of noncondensable gases in discharges from hydrothermal systems is important in several aspects of geothermal development. In power plant applications, optimization of turbine exhaust pressure is highly sensitive to the quantity of noncondensable gas that must be removed in order to maintain condenser vacuum. Thus, a knowledge of noncondensable gas concentrations is required in initial plant design. Because the concentration of noncondensable gases in discharges from hydrothermal reservoirs changes with time, continuous monitoring is required to ensure efficient operation of the condenser system of a power plant. A knowledge of the history of noncondensable gas concentrations present in the discharge from a hydrothermal system throughout the production lifetime is also important in many aspects of reservoir engineering (e.g., development of reservoir models, determination of reservoir properties, formulation of production strategies, etc.).

Chemical and separation/volumetric displacement techniques are currently used to measure the concentration of noncondensable gases in geothermal discharges. Neither of these techniques are suitable for making instantaneous measurements or for continuously monitoring levels of noncondensables. The

chemical technique requires laboratory analysis of a sample, and thus normally precludes on-site analysis. The separation/volumetric displacement technique requires a rather large equipment setup and also requires a source of cooling water.

The operation of the instrument is based upon partial pressure/perfect gas mixture principles. In a mixture of substances which can be idealized as perfect gases, the ratio of the partial pressure of a component to the total pressure of the mixture is equal to the mole fraction of the component in the mixture. Thus, by determining the noncondensable gas and steam partial pressures in a geothermal discharge, and by assuming the discharge to be a mixture of perfect gases, the molar ratio (and thus the volumetric ratio) of noncondensable gases to steam in the vapor phase of the flow can be determined.

The device used to determine the required pressures consists of a small capsule inserted into a section of pipe. The capsule, partially filled with water having boiling point characteristics representative of that being sampled, is vacuum-sealed. Pressure taps are connected to the capsule and to the wall of the pipe. As a saturated geothermal discharge is circulated through the pipe, the water in the capsule is heated to the temperature of the mixture and thus it exerts a pressure equal to the saturation pressure of water at the mixture temperature. The static pressure port in the wall of the pipe is exposed to the total pressure of the steam/noncondensable gas mixture. By measuring these two pressures, the molar ratio of noncondensable gas to steam can be determined.

In conjunction with additional measurements, the device can be used to determine the total noncondensable gas concentration (both that dissolved in the liquid phase and that in the vapor phase) in a two-phase geothermal discharge. In addition to device vapor phase noncondensable gas determination, chemical measurements to ascertain liquid phase noncondensable gas content and calorimetry measurements to determine flow steam quality (or enthalpy) are required.

The results of the laboratory and field testing have demonstrated the operability and versatility of the instrument developed during the program. Prior to commercialization of the device, it will be necessary to implement further design refinements required to improve performance and measurement accuracy. Necessary modifications and recommended additional development

testing are discussed within the report.

1.0 INTRODUCTION

1.1 Project Description

This project was a four quarter, multi-task program to develop an instrument which can continuously monitor the concentration of noncondensable gases in the vapor phase of geothermal discharges. A device having this capability would be valuable in many aspects of geothermal resource utilization (e.g., reservoir modeling and management, power plant design and operation, etc.).

The first task of the project, accomplished during the first quarter, consisted of completing the engineering design of the measurement device. During the second project quarter, procurement of materials for and fabrication of two instrument assemblies were completed. Laboratory testing (and device modification dictated by test results) of one unit was conducted during the second, third, and fourth quarter of the project. Field testing and demonstration of both units were completed at geothermal sites in the United States and in New Zealand during the final project quarter.

1.2 Instrument Application

Natural hydrothermal systems commonly contain quantities of noncondensable gases which are dissolved within the liquid water phase normally existing in high temperature, high pressure geothermal reservoirs. These noncondensable gas mixtures usually consist of carbon dioxide (typically 95 percent by weight), hydrogen sulfide (typically 3 to 4 percent by weight), and traces of other gases including nitrogen and hydrogen.

For discharges from high pressure, high temperature reservoirs, the flowing pressure drop through the bore is usually sufficient to yield a steam or steam/liquid mixture at the wellhead. The solubility of the gases within the liquid phase of the geothermal discharge at wellhead conditions is quite low and thus considerable gas is released from solution and then entrained within the steam phase.

Accurate measurement of noncondensable gas concentrations in geothermal flows is important due to the following:

1. Optimization of turbine exhaust pressure in power plant applications is sensitive to the quantity of noncondensable gas that must be removed in order to maintain the condenser vacuum.
2. Gas concentrations in a geothermal discharge typically vary with time. Continuous monitoring of the steam supply to a power station is required to ensure efficient operation of the condenser system.
3. Continuous measurement of gas

concentrations in a geothermal discharge would aid in analysis of field potentials, development of reservoir models, and management of production wells.

Another important capability of the device is that of measuring the enthalpy (or quality) of a two phase sample flow. This is accomplished by obtaining noncondensable gas concentration measurements at at least two different sample pressures (by throttling the sample flow). The enthalpy of the flow is then calculated from the noncondensable gas concentrations and from steam quality versus throttling considerations. The accuracy of enthalpy measurements using this technique is a function of the sample pressure and quality and of the noncondensable gas concentration in the flow. A discussion of sample flow conditions which enable reasonably accurate determination of enthalpy using this technique is included in the Discussion of Device Capabilities section of the report. Calculation details for the technique are included as Appendix 1.

1.3 Theory of Operation

For a mixture of gases which can be idealized to be a mixture of independent substances, the total pressure of the mixture is equal to the sum of the partial pressures of each gas component.¹ If the gas components can be idealized as perfect gases, the ratio of the partial pressure of a component to the total pressure of a mixture is equal to the mole fraction of the component in the mixture. For a mixture of gases which deviate from ideal behavior, component mole fractions can also be determined from partial pressure considerations. This is accomplished by use of ideal gas equations of state corrected for non ideal behavior via the introduction of suitable compressibility factors. Thus, by determining the noncondensable gas and steam partial pressures in a geothermal discharge, the molar ratio (and thus the volumetric ratio) of noncondensable gases to steam in the flow can be determined.

The device used to determine the required pressures consists of a small capsule inserted into a section of pipe. The capsule, partially filled with water having boiling point characteristics representative of that being sampled, is vacuum sealed. Pressure taps are connected to the capsule and to the wall of the pipe. As a geothermal discharge is circulated through the pipe, the water in the capsule is heated to the temperature of the mixture and thus it exerts a pressure equal to the saturation pressure of water at the mixture temperature. The static pressure port in the wall of the pipe is exposed to the total pressure of the steam/noncondensable gas mixture. By measuring these two pressures, the molar ratio of noncondensable gas to steam can be determined. The configuration of the device is schematically presented in Figure 1.

¹The partial pressure of a gas component is defined as the pressure of the component if it occupied the same volume as the mixture at the mixture temperature.

FIGURE 1: Instrument Schematic

1.4 Design Specifications

The design specifications for the gas concentration measurement device, mutually formulated by Terra Tek, Inc., and Lawrence Berkeley Laboratory prior to project initiation, are included in Appendix B to Subcontract No. 3976822 between the Regents of the University of California and Terra Tek, Inc. These specifications are as follows:

Design Maximum Operating Conditions -

Temperature - 419°F (215°C)
Pressure - 290 psi (20 bars)

Sample Steam Qualities -

0 - 100 percent

Differential Pressure Measurement Ranges -

0 - 20 in. H₂O (0 - 50 cm H₂O)
0 - 200 in. H₂O (0 - 500 cm H₂O)

Resolution (Differential Pressure Measurement)-

0-20 in. H₂O range - 0.02 in. H₂O (0.5 mm)
0-200 in. H₂O range - 0.2 in. H₂O (0.5 cm)

Accuracy Requirements (Differential Pressure Measurement) -

± 0.5 percent of full scale reading

Accuracy Requirements (Gas Concentration Measurement) -

± 6 percent (for a 0.1 weight percent gas concentration at a total pressure of 145 psi)

2.0 DESIGN AND CONSTRUCTION

2.1 Drawing List

Outlined in Table 1 is a listing of the detail, assembly, and installation drawings for the device. Copies of these drawings are included in Appendix 2.

TABLE 1
DRAWING LIST

Drawing No.	Sheet No.	Rev.	Title
400001	1	1	Gas Probe Unit Assembly
400001	2	0	Gas Probe Unit Assembly
400002	1	1	Transmitter Hydraulic Connection Diagram
400003	1	0	Capsule Subassembly
400004	1	1	Test Capsule Diaphragm Subassembly
400005	1	1	Static Pressure Tap Diaphragm Subassembly
400006	1	0	Heat Shield Subassembly
400007	1	0	Body Subassembly
400008	1	0	End Block Subassembly
400009	1	0	Capsule End Plug
400010	1	0	Capsule Body
400011	1	0	Capsule Tubes
400012	1	0	Heat Shield
400013	1	0	Fins
400014	1	0	Heat Shield Locating Pins
400015	1	0	Body
400016	1	0	Flange
400017	1	0	End Block
400018	1	0	Diaphragm Plug
400019	1	1	Diaphragm Body
400020	1	1	Support Gussets
400021	1	0	Support Frame
400022	1	0	Support, Instrumentation, and Insulation Installation
400023	1	0	Static Pressure Tap Assembly
400024	1	0	Details - Static Pressure Tap Diaphragm

2.2 Device Description

2.2.1 Vessel and Capsule

The general configuration of the vessel and of the capsule is outlined in the gas probe assembly drawing (400001). As can be seen in this drawing, 316 stainless steel is used in all pressure boundary parts and internal fittings.

The test section of the vessel consists of 2 inch diameter schedule 40 pipe. The inlet line to the vessel is reduced to 1 inch diameter schedule 40 pipe to match the size of typical wellbore sampling ports. The transition from 2 inch to 1 inch pipe is made with a concentric reducer to ensure that uniform test sample flows exist in the test section during operation. A globe valve rated for 300 psi service is located in the inlet line to enable throttling of the sample flow and isolation of the test vessel. A 1 inch threaded union is placed at the end of the inlet line to enable coupling of the device to wellbore sampling lines.

Access to the internal portion of the vessel is facilitated by a connection situated at the end of the test section consisting of a flat-faced flange, steam gasket, and an end block secured by six 1/4 inch diameter cap screws. The vessel exit line, welded to the end block, is 1/2 inch schedule 40 pipe. A 300 psi gate valve is located in the exit line to enable flow control and vessel isolation.

The capsule, detailed in Drawing 400003, consists of a section of 0.375 inch diameter x 0.035 inch wall tubing with ellipsoidal heads welded to each end. Two 0.125 inch diameter x 0.035 inch wall tubes are connected to the capsule for the purpose of initial capsule filling and for capsule pressure measurement. These tubes are welded to the end block portion of the vessel where penetration holes have been made. A shutoff valve is screwed into the end block into the fill line penetration. The pressure measurement instrumentation is plumbed to the lower penetration with compression fittings and .125 inch diameter tubing.

A heat shield constructed from 1.250 inch diameter x .049 wall tubing is situated between the capsule and the vessel to minimize radiation heat loss from the capsule during operation. The heat shield is supported within the vessel by four locating fins positioned at the upstream end of the shield which are secured by grooves within the vessel flange. The test capsule is supported within the shield by six locating fins welded to the exterior of the capsule.

The static pressure tap portion of the device is located in a straight section of 1 inch schedule 40 pipe, 22 inches long, positioned upstream of the measurement device. A 3/16 inch diameter hole, used for static pressure measurement, is located 6 inches from the downstream end of the pipe. A straightening vane, fabricated from 3/16-inch diameter tubing, is located near the entrance to the pipe to mitigate turbulent eddy currents in the flow in the

vicinity of the pressure tap hole.

To isolate the sample flow from the pressure measurement instruments, a diaphragm assembly is connected to the static pressure tap. The diaphragm within the assembly was fabricated in a thin-walled, cylindrical shape using silicone rubber. The pressure measurement transmitters are plumbed to the isolation diaphragm assembly using compression fittings and 0.125 inch diameter tubing. The configuration of the diaphragm allows precise transmission of static pressure to the pressure transmitters without having fluid temperature effects in the closed transmitter/tubing/diaphragm assembly fluid circuit.

2.2.2 Instrumentation

To determine the gas concentration in a sample flow passing through the unit, two pressures must be measured. These pressures are:

- 1) The differential pressure between the capsule and the sample flow (static).
- 2) The absolute pressure existing within the test capsule.

Three pressure transmitters were selected to measure the required pressures - two differential measurement units and one absolute measurement unit. Two differential units were required due to the wide range of gas concentrations (and resulting wide range of differential pressures) which the device is designed to measure. Following is information relating to the selected transmitters:

Differential Transmitter (Low Range)

Manufacturer: Viatran Corp.
Model No: 704-115
Range: 0-50 inches water (differential)
Input: 105-115 volts AC or 10-14 volts DC
Output: 0-5 volts DC
Accuracy: ± 0.25 percent of full scale reading

Differential Transmitter (High Range)

Manufacturer: Viatran Corp.
Model No.: 704-115
Range: 0-25 psi (differential)
Input: 105-115 volts AC or 10-14 volts DC
Output: 0-5 volts DC
Accuracy: ± 0.25 percent of full scale reading

Absolute Transmitter

Manufacturer: Viatran Corp.
Model No.: 701-115
Range: 0-300 psia
Input: 105-115 volts AC or 10-14 volts DC
Output: 0-5 volts DC
Accuracy: ± 0.25 percent of full scale reading

Manufacturer's specification sheets for the above units are included in Appendix 3.

Differential pressure transmitters with ranges larger than those outlined in the design specifications were selected to expand the measurement range of the device. As presented in the Discussion of Device Capabilities section of this report, instrument measurement accuracy remains within specification even with the expanded differential pressure measurement ranges.

A 100 ohm platinum resistance thermometer probe has been provided to measure the temperature of the sample flow. Measurement of the flow temperature is required to:

- 1) verify that the sample flow contains saturated steam and
- 2) verify the capsule absolute pressure measurement.

The temperature probe is inserted into the vessel upstream of the test capsule. The probe has a standard calibration accuracy of $\pm 2^{\circ}\text{F}$ at 400°F .

2.2.3 Installation

Drawings 400002 (Transmitter Hydraulic Connection Diagram), 400021 (Support Frame), and 400022 (Support, Instrumentation, and Instrumentation Installation) depict the installation scheme for the instrument. The installation details are as follows:

- 1) A triangular support frame is attached to two support gussets which are welded to the gas probe assembly.
- 2) Collars are welded to the sides of the support frame for use with support legs. Setscrews in the collars allow adjustment of the height of the unit.
- 3) The pressure transmitters are mounted on the front of the triangular frame. The transducers are connected to the appropriate pressure taps with 1/8 inch diameter stainless steel tubing.
- 4) To mitigate the effect of heat loss upon the accuracy of gas concentration measurement, the test vessel is insulated with 5 inches of refractory fiber. The insulation is applied in one inch layers banded as required with tie wires. The exterior of the insulated unit is covered with removable aluminum jacketing material.

2.3 Fabrication Procedure

Commercial hardware has been utilized in the gas probe design wherever possible. The only parts of the assembly requiring major machining or fabrication are the end block, flange, isolation diaphragm and housing, and the capsule end plugs.

Welded, threaded, or flanged connections are utilized in the assembly of the device. Shielded arc welding using E-316 filler metal is specified for all welded connections. Fabrication of the device proceeds as follows:

- 1) Individual parts detailed in drawings 400009 through 400019 are produced. The vessel flange and end block are machined integrally to ensure alignment at assembly.
- 2) Subassemblies detailed in drawings 400003 through 400008 are completed.
- 3) The gas probe unit is assembled per drawing 400001.
- 4) Transmitter and support frame installation is completed per drawings 400002 and 400022.
- 5) Insulation and jacketing is installed on the unit per drawing 400022.

3.0 TESTING PROGRAM

3.1 Laboratory Testing

3.1.1 Test Program

The primary objectives of the laboratory test program were as follows:

- 1) To demonstrate the operability of the measurement device (or identify and perform modifications required to make the device operable).
- 2) To experimentally determine the measurement accuracy of the instrument.

To meet the objectives, the testing program was divided into the following tasks:

- 1) Determine the performance characteristics of the diaphragm used to isolate the vessel from the pressure transmitters.
- 2) Verify the performance of the capsule portion of the instrument.
- 3) Determine the effect of steam flow rate upon the measurement accuracy of the device.
- 4) Verify pressure transmitter performance specifications.
- 5) Establish comprehensive procedures for device startup and operation.

3.1.2 Test Apparatus

Outlined in Figure 2 is a schematic of the apparatus constructed at the University of Utah for the purpose of conducting startup and calibration testing of the measurement instrument. Photographs of the installation are included as Figures 3 and 4. Following is a description of the apparatus.

Saturated steam with a quality of approximately 100% and at a temperature of approximately 275°F was supplied to the unit through one inch schedule 40 piping. Valves used for regulation and isolation of the steam flow were located at

FIGURE 2. Laboratory Test Apparatus Schematic

the inlet and outlet of the device and in the steam supply line. Pressure and temperature gauges were positioned approximately twenty feet upstream of the device in the steam supply line.

After passing through the measurement instrument, the steam flow was condensed in a water-cooled heat exchanger. The condensate was discharged into a tank situated on a weighing scale for the purpose of measuring the steam flow rate.

Carbon dioxide was injected into the steam supply line at a point approximately ten feet upstream from the unit. The CO₂ was supplied from a regulated, high pressure container. Gauges were located in the CO₂ line to measure temperature and pressure. The CO₂ flow rate was measured by a shielded rotameter. CO₂ was regulated by a needle valve located in the supply line downstream of the rotameter.

Output from the pressure transmitters on the device was measured using a 5-1/2 digit multimeter and using a two-channel strip chart recorder. Temperature probe resistance was also measured using a 5-1/2 digit multimeter.

3.1.3 Test Procedures

The following procedures were developed to accomplish previously outlined tasks 1, 2, and 3:

3.1.3.1 Diaphragm Performance

- 1) Fill the static pressure tap diaphragm housing, connecting tubing, and differential pressure transmitter housings with water.
- 2) With the capsule and the vessel vented to ambient, zero and calibrate the differential pressure transmitters.

FIGURE 3. Laboratory Test Apparatus

FIGURE 4. Laboratory Test Apparatus

- 3) Temporarily install a water manometer and a pressure gauge to read vessel pressure.
- 4) With the capsule side open to ambient, pressurize the vessel over a range using the CO₂ delivery system. Record transmitter outputs and corresponding pressure gauge and/or manometer readings at each specific vessel pressure.

3.1.3.2 Capsule Performance

- 1) Fill the capsule, connecting tubing, and the differential and absolute pressure transmitter housings with water.
- 2) With the capsule and vessel vented to ambient, zero and calibrate the differential and absolute pressure transmitters.
- 3) Isolate the capsule. Initiate steam flow to the vessel.
- 4) After thermal equilibrium has been obtained, vent the capsule for approximately two to three seconds.
- 5) Record pressure transmitter output and vessel flow temperature over a range of vessel static pressures (achieved by throttling the flow at the inlet to the device.)

3.1.3.3 Device Accuracy and Flow Effects

- 1) Complete setup of the capsule and static pressure fluid circuits.
- 2) Obtain steady state data (flows, temperatures, and pressures) for vessel flows containing a range of CO₂ concentrations with the steam supply fully open.
- 3) Repeat step 2 at two intermediate steam flows (approximately 20% and 50% of the maximum flow). Throttle the flow on the outlet side of the vessel.

3.1.4 Results

3.1.4.1 Diaphragm Testing

Initially, a commercially available diaphragm was used in the static pressure tap fluid circuit. The diaphragm was fabricated from silicone rubber in the form of a thin-walled disc.

During initial testing, a problem with this diaphragm configuration was identified. Upon filling and purging the pressure transmitters and associated connecting tubing with water up to the isolation diaphragms, the output from the differential pressure transmitters was found to vary considerably with time (with the capsule and the vessel vented to ambient). Previous testing of the empty transmitters indicated very little zero drift with time. Presented in Figures 5 and 6 are curves depicting the output voltage versus time of both differential transmitters following fill.

The identified problem was diagnosed as a dependence of transmitter output upon the temperature of the fill liquid. This dependence was due to the inability of the closed transmitter/connecting tubing/isolation diaphragm system to change in volume (without deflection of the transmitter diaphragms) as the volume of the purge liquid varied with change in temperature. This resulted because the isolation diaphragm was unable to increase system volume with change in fluid temperature.

To correct the identified problem, the current isolation diaphragm concept was formulated. A cylindrically-shaped diaphragm which collapses upon application of a positive pressure gradient (from the outside to the inside of the diaphragm) was selected. Testing indicated that the diaphragm was able to compensate the volume of the transmitter/tubing fluid circuit as required with change of the fluid temperature. Output versus time (with the redesigned isolation diaphragm installed) of the differential pressure transmitters following fill is presented in Figures 5 and 6.

FIGURE 5. 0-50 in H₂O Differential Pressure Transmitter Output versus Time.

FIGURE 6. 0-25 psi Differential Pressure Transmitter Output versus Time.

Response characteristics of the redesigned isolation diaphragm/pressure transmitter system were determined by venting the capsule side of the transmitters while pressurizing the vessel. A pressure gauge with 1/4 psi divisions and a vertical water manometer with 1/10 inch divisions were also connected to the vessel during the test. Indicated in Figures 7 and 8 are the transmitter outputs versus the manometer/pressure gauge outputs over a range of vessel pressures.

As can be seen from these figures, the measurement accuracy of the 0-50 in. H₂O transmitter/isolation diaphragm is well within the accuracy of the water manometer over the pressure range of 0-20 in. H₂O. The measurement accuracy of the 0-25 psi transmitter/isolation diaphragm is within 8% even over the 0-20 in. H₂O pressure range. Over a 2-25 psi pressure range, the 0-25 psi transmitter was found to be accurate within 3.3% when calibrated to the low range.

3.1.4.2 Capsule Testing

Capsule testing was conducted per the previously outlined procedure. Presented in Figure 9 is a curve depicting capsule absolute pressure (as indicated by the 0-300 psia pressure transmitter) versus the steam saturation pressure (corresponding to the temperature of the flow measured by the resistance thermometer over a range of flow temperatures).

FIGURE 7. Pressure Transmitter Output versus Applied Pressure (High Range)

FIGURE 8. Pressure Transmitter Output versus Applied Pressure (High Range)

FIGURE 9. Capsule Pressure versus Flow Saturation Pressure

As shown in the figure, capsule pressure ceases to correspond to saturation pressures which are below atmospheric pressure. This is probably due to either incomplete purging of the capsule circuit or to vacuum leakage in the capsule circuit when pressures are below atmospheric. Because the measurement device will not be required to operate at conditions which will create sub-atmospheric pressures in the capsule, this is not considered to be a problem. The capsule was found to perform properly at temperatures above 212°F after being cooled to room temperature (creating a vacuum within the capsule), however.

For testing with saturation pressures ranging from 20-45 psia, the capsule pressure as measured with the 0-300 psia pressure transmitter agreed with the steam saturation pressure inferred from the resistance temperature probe within 8.6%.

3.1.4.3 Device Accuracy and Flow Effects

Initially, the static pressure tap consisted of a piece of 1/4 inch diameter tubing penetrating into the inner surface of the heat shield assembly. This pressure tap was adjacent to the center of the capsule assembly.

While preparing for functional testing with steam/CO₂ injection, the device was operated with steam flow only. During this period, the output from the differential pressure transmitters (which indicates the pressure difference between the capsule and the vessel flow) was found to change with time. Closer investigation indicated that steam supply pressure to the test apparatus (and thus test vessel velocity) was also changing with time due to inherent characteristics of the steam system.

The problem was thus diagnosed as a dependence of static pressure measurement upon test vessel steam velocity. This dependence of static pressure measurement upon velocity was due to flow interferences in the vicinity of the static pressure tap caused by the capsule and heat shield assemblies. Per Streeter (Reference 1, pg. 439) errors in static pressure measurement normally vary with velocity as follows:

$$\text{Error} = \text{const.} \times (\text{velocity})^2$$

Or by utilizing the Darcy-Weisbach equation, errors in static pressure measurement normally vary with driving head (or pressure) as follows:

$$\text{Error} = \text{const.} \times (\Delta P)$$

Included as Figure 10 is a plot of static pressure measurement error versus driving head (supply pressure minus ambient pressure) obtained during testing of the initial device configuration. As can be seen in the figure, the static pressure measurement error was essentially linear with driving head; the slope of the curve is approximately 7.1 in. H₂O/psi.

To correct the identified problem, the current static pressure tap configuration was designed. After modifying the device, steam flow

FIGURE 10. Static Pressure Measurement Error versus Driving Head (Original Pressure Tap Configuration)

testing was conducted. During this testing, dependence of differential pressure transmitter output upon driving head was again observed, although the dependence was much less than that of the previous design.

Included as Figure 11 is a plot of static pressure measurement error versus driving head data obtained following installation of the redesigned pressure tap. Again, the pressure measurement error was essentially linear with driving head; the slope of the curve is approximately 0.8 in. H₂O/psi.

After conducting steam flow testing of the device (with the redesigned static pressure tap installed), functional testing with steam/carbon dioxide flows was performed. The device was operated with a steam supply pressure of approximately 50 psia (corresponding to a saturation temperature of 281°F). The CO₂ concentration in the flow mixture was varied from between 1 and 10 percent by weight during testing. The device was operated with no throttling of the flow; the average steam flow rate through the device was approximately 0.15 lb/sec.

Depicted in Figure 12 is a plot of CO₂ concentration per the measurement device versus the CO₂ concentration determined by measurement of steam and CO₂ flows. This curve was generated

FIGURE 11. Static Pressure Measurement Error versus Driving Head (Redesigned Pressure Tap Configuration)

FIGURE 12. CO₂ Concentration per Device versus CO₂ Concentration per Flow Measurement (Steam Flow Rate = 0.15 lb/sec)

FIGURE 13. CO₂ Concentration per Device versus CO₂ Concentration per Flow Measurement (Steam Flow Rate = .01 lb/sec)

from data obtained during testing at the aforementioned conditions. As seen in the figure, measurement errors as large as 45 percent were incurred during the testing.

In view of recognized velocity dependence problems and due to the discrepancy in device measurement exemplified in Figure 12, it was decided to conduct a series of steam/CO₂ flow tests with low steam flow rates. Testing was performed with a steam supply pressure of approximately 60 psia and a steam flow rate of approximately 0.01 lb/sec. Included as Figure 13 is a summary of the data obtained during the testing.

Testing conducted at low sample flow rates yielded reasonable agreement between the device gas concentration measurement and the gas concentration indicated by flow measurement. Agreement between the two measurements was within 10 percent for gas concentrations ranging from between two and eight weight percent.

3.2 Field Testing

3.2.1 Field Testing - U.S.

3.2.1.1 Test Program

The primary objectives of the field testing program were as follows:

- 1) To demonstrate the operability of the device in a variety of geothermal environments.
- 2) To verify device measurement accuracy in a variety of geothermal environments using an alternate measurement technique.

A series of field tests at Roosevelt (Phillips Petroleum Company) and the Geysers (Union Oil Co.) were conducted to meet the outlined objectives.

3.2.1.2 Test Apparatus

Outlined in Figure 14 is a schematic depicting the configuration of the apparatus set up at each test site. Photographs of the installations at Roosevelt and the Geysers are included as Figures 15 and 16, respectively.

A separation/condensation/volumetric displacement noncondensable gas concentration measurement technique was selected for verifying the measurement accuracy of the device. The hardware required for the alternate scheme was connected in parallel to the measurement device.

FIGURE 14. Field Test Apparatus Schematic

The measurement device was plumbed to the proximity of the main wellhead discharge line with 1 inch piping components. Final attachment to the sampling port on the main line was made with flexible hose to eliminate the transmission of vibration to the instrumentation. A dial pressure gauge was located in the sample line to enable determination of steam conditions (in conjunction with device instrumentation). The sample flow was discharged to ambient surroundings after passing through the instrument.

The hardware for the alternate scheme consisted of a Webre-type separator, a condenser coil immersed in a water-filled drum, a condensate collection graduated cylinder, and a graduated gas collection drum. The two-phase sample flow from the wellhead was first circulated through the separator, where it was divided into two single phase flows -- one consisting of water and one consisting of a mixture of steam and noncondensable gases. The steam/noncondensable gas flow from the separator

FIGURE 15. Roosevelt Test Apparatus

FIGURE 16. Geysers Test Apparatus

was then circulated through the immersed tubing coil where the steam was condensed. The water flowing from the coil was collected in a graduated cylinder; the noncondensable gases in the flow displaced a measured volume of water in the graduated drum. By measuring the condensate volume and noncondensable gas volume collected over a period of time, the ratio of noncondensable gas to steam in the sample flow was determined.

3.2.1.3 Roosevelt Testing

3.2.1.3.1 Test Procedure and Results

Testing using the instrument and using the alternate scheme was conducted in the Roosevelt Geothermal Field on a well owned by Phillips Petroleum Company. Data was collected using a sample flow from the main wellhead discharge line (containing two-phase flow) and on the steam line located downstream of the separator.

Testing conducted on both sampling ports consisted of obtaining gas concentration measurements using the instrument and using the alternate scheme over a range of sample pressures. At each test condition, instantaneous output from the instrument was recorded for a period of time sufficient to ensure that a representative average noncondensable gas concentration measurement was obtained. With the alternate scheme, each measurement was obtained over a 10 to 15 minute sampling period. Measurements using the two techniques were not made simultaneously. Also, one long term test (approximately 12 hours) was conducted on the steam sampling port using the device.

Due to the range of the absolute pressure transmitter installed on the instrument, testing could not be conducted at full line pressure. Sample flows were throttled at the entrance to the test apparatus to keep pressures within the range of the transmitter. Noncondensable gas concentrations at line conditions were extrapolated from the test data, however.

Included as Figure 17 is a comparison of noncondensable gas concentration measurements made on the two phase line using the device and using the alternate scheme. Figure 18 presents a comparison of measurements made on the steam line. Although measurements using both techniques were not made simultaneously, comparison is warranted due to the consistency of wellhead flow conditions throughout testing. In both of these figures, actual sample pressures have not been specified. Also, molar noncondensable gas to steam concentrations have been multiplied by an unspecified constant. The results have been presented in this manner per the request of Phillips Petroleum Company due to the proprietary nature of the information. During the 12-hour instrument test on the steam line, data consistent with those of the short term tests were obtained throughout the testing period.

Conditions in the two-phase line were such that the enthalpy (or quality) of the sample flow could be calculated from the noncondensable gas

FIGURE 18. Roosevelt Field Test Data-Steam Sampling Port

FIGURE 17. Roosevelt Field Test Data - Two Phase Sampling Port

concentration data obtained at different sampling pressures. Again, the actual data cannot be presented due to proprietary considerations. However, deviation between the steam quality values calculated from data obtained using the two techniques was less than 5%.

3.2.1.3.2 Discussion of Results

As shown in Figure 17, gas concentrations measured during testing on the main wellhead discharge line using the device were somewhat higher than those measured using the alternate scheme. In extrapolating the results to line conditions, there is a 25% variation in noncondensable gas concentrations determined using the device and using the alternate scheme. There are two possible causes for the disparity between the two measurements:

- 1) Due to the quality of the sample flow, in using the small Webre separator installed in the apparatus, it was difficult to obtain a dry steam sample. Thus, there was probably some liquid carryover in the steam discharging from the separator, causing a low noncondensable gas to steam ratio to be measured using the alternate scheme.
- 2) Considerable fluctuation in the differential pressure output from the device was observed during testing. This fluctuation was caused by variation in the static pressure measurement caused by flow conditions. Noncondensable gas concentrations were calculated using the average of the minimum and maximum differential pressure observed during the testing period. Integration of the differential pressure output during the testing period would yield more precise noncondensable gas concentration measurements.

Per Figure 18, there was a considerable difference between the noncondensable gas concentration measurement obtained using the device and using the alternate scheme while testing on the steam line located downstream of the separator. In comparing the data with the results from testing on the two-phase line, it appears that the device measurement is in error. It is hypothesized that the discrepancy is caused from sampling of a superheated flow (due to the boiling point loss at separation and due to throttling of the sample flow between the main line and the device). When the device is used to measure superheated flows, low noncondensable gas concentration measurements result due to generation of erroneously high steam partial pressures in the capsule portion of the device. Superheating on the order of 1°F would account for the discrepancy observed during testing. Unfortunately, the precision of instrumentation installed in the test apparatus was not sufficient to determine if superheating of the sample flow occurred.

3.2.1.4 Geysers Testing

3.2.1.4.1 Test Procedure and Results

Testing using the instrument and using the alternate scheme was conducted in the Geyser's Geothermal Field on a well owned by Union Oil Company. Nominal conditions of the discharge from the well were as follows:

Pressure - 133 psig
Quality - 95.8 - 98.5 percent (Union Oil Measurement)

Per Union Oil personnel at the site, quality of the well discharge was last measured during September, 1978.

Sample flows were tapped from a port located on the main wellhead discharge line upstream of the separator. All testing was conducted with sample flows at essentially the same pressure as the main wellhead line (negligible throttling of the sample flow existed due to the flow rates present and due to the configuration of the test apparatus). Unfortunately, it was not possible to operate both the instrument and the alternate measurement apparatus simultaneously due to throttling considerations.

On the first afternoon of testing, a series of measurements were made using the alternate scheme. Sampling periods for these measurements ranged from between 5 to 30 minutes. Two additional measurements using the alternate scheme were made during the following two days of testing. A summary of the measurements made using this technique are included in Table 2.

TABLE 2
NONCONDENSABLE GAS CONCENTRATION MEASUREMENTS
VIA ALTERNATE SCHEME - GEYSERS TESTING

RUN NO.	SAMPLING PERIOD (Minutes)	SAMPLE PRESSURE (psig)	MOLAR RATIO * (NONCONDENSABLES TO STEAM)
10/2/79 1	27	133.0	3.42×10^{-3}
2	12	132.6	2.82×10^{-3}
3	5	132.0	2.50×10^{-3}
4	6	132.1	2.75×10^{-3}
10/3/79 1	6	130.0	2.51×10^{-3}
10/4/79 1	25	113.0	2.55×10^{-3}

*Calculated assuming atmospheric pressure of 14.7 psia.

On the second day of testing, noncondensable gas concentration measurements were made using the instrument. Data from the device (capsule pressure and differential pressure via the low range transmitter) were continuously recorded for a period of approximately six hours. Included as Figure 19 is the actual output from the device over the testing period. Table 3 presents calculated values of noncondensable gas concentrations at selected times during the test (as denoted by run numbers in Figure 19). Due to a calibration problem with the 0-50 in. H₂O differential pressure transmitter (caused by exposing the transmitter to a high vacuum during overnight shutdown), output from the 0-25 psi differential transmitter was recorded during the third day of testing. Data over a two hour testing period is included as Figure 20. Calculated values of noncondensable gas concentrations during this period are presented in Table 4.

FIGURE 19. Device Output at Geysers - 0-50 in. H_2O Pressure Transmitter

FIGURE 20. Device Output at Geysers - 0-25 psi Pressure Transmitter

TABLE 3
NONCONDENSABLE GAS CONCENTRATION MEASUREMENTS
VIA DEVICE (USING LOW RANGE TRANSMITTER)

RUN NO.	NONCONDENSABLE GAS PARTIAL PRESSURE (psi)	STEAM PARTIAL PRESSURE (psi)	MOLE FRACTION (NONCONDENSABLE GAS TO STEAM)
4	0.47	136.04	0.0035
5	0.13	137.83	0.0009
6	0.51	128.88	0.0040
7	0.36	119.33	0.0030
8	0.48	121.12	0.0040
9	0.36	123.51	0.0029
10	0.54	125.30	0.0043
11	0.61	122.32	0.0050
12	0.94	122.91	0.0077
13	1.44	126.49	0.0114
14	1.55	125.90	0.0123
15	1.70	127.09	0.0134

TABLE 4
NONCONDENSABLE GAS CONCENTRATION MEASUREMENTS
(HIGH RANGE TRANSMITTER)

RUN NO.	NONCONDENSABLE GAS PARTIAL PRESSURE (psi)	STEAM PARTIAL PRESSURE (psi)	MOLE FRACTION (NONCONDENSABLE GAS TO STEAM)
1	0.980	122.32	0.0080
2	0.905	123.51	0.0073
3	0.805	123.51	0.0065
4	0.805	123.51	0.0065
5	0.805	124.11	0.0065
6	0.895	125.90	0.0071
7	0.980	127.09	0.0077

3.2.1.4.2 Discussion of Results

As can be seen in Figure 19 and Table 3, considerable variation in noncondensable gas concentration was observed during the second day of testing. It should be noted that well conditions also varied considerably during testing (as exemplified by the measured steam saturation pressures).

Noncondensable gas concentration measurements obtained using the instrument (using the low range transmitter) approximate those acquired from the alternate measurement scheme. Due to the variable nature of the gas concentration in the sample flow, and due to the inability to make simultaneous measurements using the device and the alternate scheme, detailed comparison of results is not warranted.

Although the measurement precision was not high using the 0-25 psi transmitter (measured differentials were less than 1 psi), the results are useful in depicting relative changes in noncondensable gas concentrations. As shown in Figure 20, fluctuations in measured noncondensable gas concentrations during the third day of testing

were much lower than those observed during the previous day's testing. Also, it should be noted that line conditions were much more stable during the third day of testing.

3.2.2 Field Testing - New Zealand¹

The major start on the project in New Zealand began in September 1979 with the arrival of the capsule unit and the pressure transducers.

The transducers were converted to 12 v DC operation; the two differentials maintaining their scales of 0-50" and 0-25 psi. However the 300 psi total pressure transducer changed calibration slightly to 2.22 volts at 150 psi instead of 2.5 volts.

A sophisticated test unit is required to recalibrate this unit to avoid contamination within the diaphragm cell. So, until such a unit can be adapted, it was decided to carry on testing with a master gauge on the steam/water line.

On receipt of the new type isolating diaphragm the unit was set up.

One major change from the American unit was the static pressure tap on the high pressure side of the transducers.

Pressure tapping geometry as tested and published by Livesey Jackson & Southern - "Static hole error problem" - Aircraft Eng. Vol. 34, 1962, was incorporated.

This tapping has been found to be most satisfactory and is used exclusively by D.S.I.R. Wairakei and University of Auckland researchers in dynamic steam/water mixture pressure readings.

Instrumentation was completed by a digital voltmeter in parallel with an Eastline Angus 4" paper recorder model MS411B. A four way switch was built into the circuit to read the three transducers and battery voltage.

The first test run was at Broadlands Bore
27. Pressure 10.7 Bar, Gauge 155 psig, Enthalpy 709 BTU/lb, Dryness fraction 0.47.

One continuous reading was taken over a 20 minute period, the 25 psi differential transducer settling down to a plus or minus 25 Mv reading relatively fast.

A senior chemical sampling technical officer took three flasks of separated steam using the Webre separator. The results were:

Flash 1	Flash 2	Flash 3	Gas Unit
Mole % 4.25063	5.65632	5.8011	5.82

The chemists acknowledge that our reading of 5.82 mole percent is the most correct considering residual gases (a very minor percentage) which

were not determined by them.

As the unit was not rechargeable in the field, it was taken back to the Lab and modified for easier refilling. This consisted of the addition of a valve and a bleed point, both of which can be plugged after filling.

The remaining tests were run at Broadlands
22. 10 Bars, 145 psig, Dryness 99%; gas variable as required.

The test was reasonably successful; the partial pressure of the gas reading 0.64 volts (3.2 psi) was obtained within 3 minutes. However, after a further 5 minutes all the differentials drifted to read negative readings over a short period.

Several reruns were made achieving similar results.

The unit was set up over a 48 hour period in the laboratory. The capsule unit filled with distilled water pressurized by air and plugged as per procedure, the static tapping side also filled with water and pressurized by air and sealed the differential maintained a reading of 12.5 psi over the whole period and the total tapping pressure maintained 80 psi.

At no time was drift noticed.

A second test was set up again at 80 psi total pressure with 25 inches of water differential no deviation or drift was recorded over a 48 hour period.

The only explanation for the drift to date is the environment where the test was set up.

The unit was attached to a pilot condenser unit with cooling towers etc., using 2 tons steam per hour. Conditions were wet and humid, and with 3 pumps vibration is high.

The present status of the unit is that I am awaiting the finishing of a full test shed with two water (hot at 11 Bar) two steam (11 Bar) and one gas line (25 Bar 125°C) all 1" diameter schedule 40 steam pipe. The test rig is principally for the design of a pressure tapping for steam/water flow testing orifice plates etc. but will be available to gas testing.

Both the Ministry of Works and D.S.I.R. N.Z. consider the unit to show great promise and are confident that the present problems will be easily overcome.

4.0 OPERATING PROCEDURES

The following device operating procedures were developed during the course of the laboratory and field testing program.

4.1 Initial Startup

Prior to installing insulation and jacketing on the completed gas probe assembly, it is necessary to fill and purge the capsule and static pressure tap fluid circuits with water. The

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procedure for filling is as follows:

4.1.1 Static Pressure Tap Circuit

- 1) Obtain a tank with a capacity of approximately 2 gallons having a discharge line located at the bottom.
- 2) Elevate the tank to above the device (approximately 3 feet).
- 3) Attach the discharge line from the tank to the isolation valve positioned in the lower vent port on the high pressure housing of the 0-25 psid pressure transmitter.
- 4) Isolate the vessel portion of the device. Plumb a branch line from the tank discharge line to the vessel (attached to a convenient port). (NOTE: This procedure is necessary to maintain the same pressure on both sides of the static pressure tap isolation diaphragm during fill operations.)
- 5) Fill the tank with clean water.
- 6) Remove the upper vent plug from the high pressure port housing of the 0-25 psid pressure transmitter. Open the isolation valve in the lower vent port of the same pressure transmitter.
- 7) Allow the water to flow from the 0-25 psid pressure transmitter housing for approximately 5 minutes. Reinstall the vent plug into the housing.
- 8) Remove the upper vent plug from the high pressure port housing of the 0-50 in. H₂O pressure transmitter. Allow water to flow from the housing for approximately 5 minutes.
- 9) Reinstall the vent plug on the 0-50 in. H₂O transmitter.
- 10) Remove the vent plug from the top of the static pressure tap isolation diaphragm housing. Allow water to flow from the housing for approximately 5 minutes.
- 11) Replace the diaphragm housing vent plug.
- 12) Lower the fill tank such that the water level in the tank coincides with the centerline elevation of the isolation diaphragm housing.
- 13) Close the isolation valve on the 0-25 psid transmitter housing. Remove the fill line and then securely cap the valve.
- 14) Proceed to capsule setup.

4.1.2 Capsule

- 1) Obtain approximately 2 gallons of water having boiling point properties characteristic of those of the geothermal flow to be sampled.
- 2) Place the water in a pressurizable tank having a discharge line which draws from the bottom of the tank. Pressurize the tank to approximately 30 psi.
- 3) Attach the pressure tank discharge line to the capsule fill valve located at the top of the device.
- 4) Remove the upper housing vent plug from the high pressure side of the 0-25 psid pressure transmitter.
- 5) Open the valves isolating the pressure tank from the capsule. Allow water to flow from the transmitter housing for approximately ten to fifteen minutes.
- 6) Replace the vent plug on 0-25 psid transmitter.
- 7) Remove the upper housing vent plug from the high pressure side of the 0-50 in. H₂O pressure transmitter. Allow the water to flow from the transmitter housing for approximately five minutes.
- 8) Replace the vent plug on the 0-50 in. H₂O pressure transmitter.
- 9) Loosen the lower portion of the pressure capsule housing on the 0-300 psia absolute pressure transmitter until water flow is present. Allow the water to flow for approximately five minutes.
- 10) Retighten the pressure capsule housing on the 0-300 psia transmitter.
- 11) Elevate the pressure tank to above the device.
- 12) Open the pressure tank to atmosphere. Lower the tank until the water level within it coincides with the centerline of the test vessel.
- 13) With the static pressure port open to atmosphere, zero and calibrate the differential pressure transmitters. Adjust the absolute pressure transmitter such that it reads atmospheric pressure. Also adjust the span on the absolute pressure transmitter.
- 14) Shut the capsule isolation valve. Detach the fill line from the device and then cap the valve.
- 15) Insulate the unit with 5 layers of one inch thick refractory fiber. Allow for access to the capsule isolation valve.
- 16) Initiate sample flow to the device. Allow the unit to reach thermal equilibrium (determined by monitoring capsule pressure).
- 17) Vent the capsule through the capsule isolation valve for approximately one second. Following venting, monitor

capsule pressure until an equilibrium condition is attained.

- 18) Repeat step 17 until the capsule reaches the same equilibrium pressure after two venting cycles.
- 19) Securely cap the capsule isolation valve. Add insulation in the vicinity of the isolation valve. Add the aluminum jacketing material to the exterior of the insulation.

4.2 Normal Operation

The procedure for normal operation of the measurement device is as follows:

4.2.1 Startup

- 1) Plumb the device to the line to be sampled. Make final attachment to the sampling port with a section of flexible hose to eliminate the transmission of line vibrations to the device.
- 2) Level the instrument.
- 3) Attach a suitable discharge line to the device.
- 4) Connect a 12 volt DC source to the input terminal box for the pressure transmitters.
- 5) Connect the output terminals from the pressure transmitters to a multi-pen strip chart recorder. Attach the leads from the resistance temperature probe to a digital multimeter.
- 6) Fully open the 1/4 inch needle valve located on the discharge end of the device.
- 7) Gradually initiate sample flow through the device.
- 8) Allow the unit to reach thermal equilibrium. Commence recording data required for determining the gas concentration of the sample flow (pressure transmitter outputs plus secondary information such as sample temperature and pressure, etc.).
- 9) Calculate sample noncondensable gas concentration per the procedure outlined in Appendix 4.

4.2.2 Shutdown

- 1) Isolate the sample flow to the vessel.
- 2) Uncouple electrical and instrumentation leads.
- 3) Detach the plumbing leading to the device.
- 4) Drain the unit, cool it to ambient temperature, and then fully close the inlet and outlet line valves.

5.0 DISCUSSION OF DEVICE CAPABILITIES

5.1 Mechanical Design

5.1.1 Materials

An austenitic stainless steel (Type 316) was the material selected for use in the instrument pressure boundary and internal fittings. This material was selected due to its corrosion resistance properties and due to its machineability and weldability.

The isolation diaphragm used in the static pressure tap line was fabricated from silicone rubber. This material was selected due to its ability to withstand high temperatures and moderately corrosive environments while maintaining flexibility.

5.1.2 Design Margins

The gas probe device will be exposed to three operating conditions -- startup, normal operation, and shutdown. Presented in Tables 5, 6 and 7 are listings of the instrument components affected during operation in each of the three modes. Also included in the Tables are listings of allowable pressures for the device components. Supplementary calculations are included in Appendix 5.

TABLE 5
GAS PROBE DESIGN PRESSURES -- COMPONENTS AFFECTED BY STARTUP

ITEM	DESIGN PRESSURE*
Capsule (Dwg. No. 400003)	Full Vacuum (See Appendix 5)
1/8" O.D. x 0.035 wall tubing	Full Vacuum (See Appendix 5)
Isolation Valve (Dwg. No. 400008-1)	Full Vacuum (Ref. Whitey Valve Co., Catalog)
Capsule Diaphragm Housing (Dwg. No. 400004)	Full Vacuum (See Appendix 5)
1/8" Swagelok Connector (Dwg. No. 400004-1)	Full Vacuum (Ref. Swagelok Co., Catalog)
1/8" Swagelok Male Connector (Dwg. No. 400002)	Full Vacuum (Ref. Swagelok Co., Catalog)
Transmitters (Dwg. No. 400002-1,2,3)	Full Vacuum (Ref. Vendor Specs., Appendix 3)

*At Startup Conditions
Startup Conditions: (1) Capsule at full vacuum
(2) Vessel at 290 psi
(3) Ambient at 14.7 psi

Prior to and at the initiation of startup, the capsule, capsule pressure tap and fill lines, and all pressure transmitters will be exposed to nearly a full vacuum. Vessel pressure will instantaneously increase to as high as 290 psi at startup (with the capsule at full vacuum).

During normal operation, the capsule and associated pressure measurement hardware will be at a pressure only slightly lower than the vessel pressure. All pressure boundary portions of the instrument vessel will be exposed to the design pressure of 290 psi.

TABLE 6
GAS PROBE DESIGN PRESSURES — COMPONENTS AFFECTED BY NORMAL OPERATION

ITEM	DESIGN PRESSURE*
1" Threaded Union (Dwg. No. 400001-1)	3000 lb. (Ref. Vogt Piping Catalog)
1" Sch. 40 Pipe (Dwg. No. 400001,2,4)	1635 psi (Appendix 5)
1" 300 lb. Globe Valve (Dwg. No. 400001-3)	300 psi (Ref. Vogt Piping Catalog)
2" Sch. 40 Pipe (Dwg. No. 400001-6)	1194 psi (Appendix 5)
Swagelok Cap Connectors (Dwg. No. 400907-3)	12,675 psi (Ref. Swagelok Co., Catalog)
Flange & End Block (Dwg. No. 400016,17)	>300 psi (Appendix 5)
Isolation Valve (Dwg. No. 400008-1)	3000 psi (Ref. Whitey Co. Catalog)
1/2" Sch. 40 Pipe (Dwg. No. 400001-10)	2117 psi (See Appendix 5)
3/4" 300 lb Gate Valve (Dwg. No. 400001-12)	300 psi (Ref. Vogt Piping Catalog)
Isolation Diaphragms (Dwg. No. 400004,5)	>300 psi (Appendix 5)
1/8" OD x 0.035 Wall Tubing (Dwg. No. 400002)	12,675 psi (Ref. Swagelok Co., Catalog)
1/8" Swagelok Male Connectors (Dwg. No. 400002)	5250 psi (Ref. Swagelok Co., Catalog)
1/4" OD x 0.049 Wall Tubing (Dwg. No. 400005-1)	8700 psi (Ref. Swagelok Co., Catalog)
Static Pressure Tap Diaphragm Assembly	>300 psi (Ref. Appendix 5)

*At Normal Operating Condition

Normal Operating Conditions: (1) Vessel pressure 290 psi
(2) Vessel temperature 420°F
(3) Ambient pressure 14.7 psi

TABLE 7
GAS PROBE DESIGN PRESSURES — COMPONENTS AFFECTED BY SHUTDOWN

ITEM	DESIGN PRESSURE*
Capsule (Dwg. No. 400003)	3,768 psi (Ref. Swagelok Co., Catalog)
1/8" OD x 0.035 wall tubing	12,675 psi (Ref. Swagelok Co., Catalog)
Isolation Valve (Dwg. No. 400008-1)	3,000 psi (Ref. Whitey Co., Catalog)
Capsule Diaphragm Housing (Dwg. No. 400004)	>300 psi (See Appendix 5)
1/8" Swagelok Connector (Dwg. No. 400004-1)	12,675 psi (Ref. Swagelok Co., Catalog)
1/8" Swagelok Male Connector (Dwg. No. 400002)	12,675 psi (Ref. Swagelok Co., Catalog)
Transmitters (Dwg. No. 400002-1,2,3)	2000 psi (Ref. Vendor Specs., Appendix 3)

*At Shutdown Conditions

Shutdown Conditions: (1) Capsule at 290 psi
(2) Vessel at 14.7 psi
(3) Ambient at 14.7 psi

At the initiation of shutdown, the capsule and associated pressure measurement hardware will be at pressures as high as the design pressure of 290 psi. The vessel pressure at shutdown will be that of the surroundings.

5.2 Measurement Accuracy - Gas Concentration

5.2.1 Theoretical Accuracy

5.2.1.1 Heat Loss Effects

In order to obtain accurate gas concentration measurements, it is essential that the test capsule be maintained at the same temperature as the geothermal flow. Very small temperature differences between the test capsule and the sample fluid cause large errors in gas concentration measurements for low gas concentration flow.

Contained in Appendix 6 are calculations which quantify the effect of vessel heat losses upon gas concentration measurement accuracy. These calculations indicate that by adding a radiation shield around the capsule and by insulating the vessel with at least five inches of refractory fiber, gas concentration measurement errors due to capsule/sample flow temperature differentials will be reduced to negligible values.

5.2.1.2 Instrumentation Effects

The pressure transmitters selected for measuring the differential pressures between the test capsule and the sample flow and for measuring the absolute capsule pressure have an accuracy of 0.25 percent of the calibrated span. Presented in Appendix 7 are curves depicting the maximum possible gas concentration measurement error due to pressure transmitter accuracy.

As can be seen in Appendix 7, it is necessary to use two differential pressure transmitters to obtain the required gas concentration measurement accuracy. By using two differential pressure transmitters (ranges 0-50 in H₂O and 0-25 psi), the error in measurement of gas concentration is less than 2 percent throughout the operating pressure range for gas concentrations of 1 percent (by weight) or greater. The error in gas concentration measurement for a flow containing 0.1 percent (by weight) noncondensable gas is less than 8 percent for steam saturation pressures of 36 psi or greater.

5.2.1.3 Boiling Point Effects

Boiling point elevation of brines due to dissolved solids has a pronounced effect upon the accuracy of the measurement device if pure, distilled water is used in the capsule portion of the unit. This effect upon measurement accuracy is quantified in Appendix 8. Due to the high sensitivity of measurement accuracy to brine composition, it is necessary to use a brine having the same characteristics as that being sampled in the device capsule.

5.2.2 Experimentally Determined Accuracy

During laboratory testing, device noncondensable gas concentration measurements were found to agree within 10 percent of measurements made via flow metering for noncondensable gas concentrations ranging from 2 to 8 percent by weight. This testing was conducted with steam saturation pressures of approximately 50 psig. As shown in Appendix 7, measurement accuracy is highly dependent upon steam saturation pressures with lower accuracy corresponding to lower pressures. Thus, the measurement error of the device would be expected to be less than 10 percent for

steam saturation pressures greater than 50 psig.

Direct comparison of device measurement with that of an alternate scheme was possible only during testing conducted at the Roosevelt Area for previously discussed reasons. During testing on a two phase line in the Roosevelt Area, extrapolation of data indicated that device measurement differed approximately 25 percent from that of the alternate technique.

As previously discussed, it is anticipated that device measurement accuracy could be improved by implementing the instrument modifications outlined in the Commercialization Plan section of this report.

5.3 Measurement Accuracy -- Enthalpy

The accuracy of the device in measuring the enthalpy (or quality) of a flow is a function of (1) the quality of the flow, (2) the ratio of noncondensable gases to steam in the flow, (3) the ratio of sample pressure to line pressure at which data is obtained, and (4) the accuracy of the device in measuring noncondensable gas concentrations. Included as Appendix 1 is a discussion of device enthalpy measurement capability.

As presented in Appendix 1, the device can measure the quality of a flow with reasonable accuracy when:

- 1) Noncondensable gas concentrations are relatively high (1 mole percent or greater).
- 2) Line steam qualities are relatively low (50 percent or less).
- 3) Small sample pressure/line pressure data ratios are possible (0.5 or less).

Testing conducted during development of the device was not sufficient to experimentally verify the enthalpy measurement capabilities of the instrument.

5.4 Device Limitations

5.4.1 Flow Velocity

With the current device configuration, there is an error in static pressure measurement which is proportional to the square of the sample flow velocity passing through the device. Associated with the error in static pressure measurement is an error in measurement of noncondensable gas concentrations. The error in measurement can be minimized by operating the device at a low, essentially constant velocity. This can be achieved by throttling the sample flow on the outlet side of the test vessel. Included in Appendix 9 are calculations outlining noncondensable gas concentration measurement errors versus sample velocity. As shown in these calculations, the device will yield acceptable gas concentration measurement accuracy if it is operated with sample velocities below 30 ft/sec in the static pressure tap pipe.

A device modification which would reduce the effect of velocity upon static pressure measure-

ment is discussed in the Commercialization Plan section of this report.

5.4.2 Two Phase Flow

Entrained liquid or mist in a two phase sample flow has the potential of producing errant static pressure measurements. This effect was illustrated during testing of the device at the Roosevelt Geothermal Area. Large fluctuations in measured sample flow static pressure were observed during testing on the two phase line. However, the average of the measured noncondensable gas concentrations approximated results obtained via an alternate measurement technique.

It is envisioned that dampening or integration of the output from the device will enable precise measurement of noncondensable gas concentrations in two phase flow. This device modification is outlined in the Commercialization Plan section of the report.

5.4.3 Phase Disproportionation

The capability of the instrument is that of measuring the molar ratio of noncondensable gases to the steam portion of a saturated steam/water geothermal discharge. No determination of the concentration of noncondensable gases dissolved within the water phase is made.

In the case of a pressurized brine being flashed (with a low percentage of steam) through the device, the equilibrium between the brine and gas phases is disproportionated. For small percentages of flashing, significant amounts of noncondensables are present in both the liquid and gas phase. Thus, chemical measurements on the brine as well as gas phase noncondensables measurements are required to determine the total amount of noncondensables in the discharge.

In sample flows which contain a substantial percentage of steam, the bulk of the noncondensable gases are present in the vapor phase of the sample flow. Per Ellis and Mahon (Reference 2, pg. 279), in a typical geothermal discharge having CO₂ as the predominant noncondensable gas, 90 percent or more of the CO₂ in the total discharge is contained within the vapor phase for flows having steam qualities of 10 percent or greater. Thus, in such flows, gas phase noncondensables measurements yield a good approximation of the amount of noncondensable gases in the total discharge.

5.4.4 Scale and Solids Deposition

During the operation of the device in a two phase flow, it is possible that scale could be deposited in the vicinity of the static pressure tap. This deposition could affect the accuracy of static pressure measurement.

The amount of field testing that has been conducted to date was insufficient to assess the effect of scaling upon device performance. If future testing indicates that a problem does exist, it will be necessary to periodically clean the static pressure tap assembly.

5.4.5 Sample Superheating

Due to the principle of operation of the device, the measurement instrument functions properly only when used to sample saturated steam/water flows. When the device is used to measure superheated flows, low noncondensable gas concentration measurements result due to the generation of erroneously high steam partial pressures in the capsule portion of the device. This problem was demonstrated during Roosevelt field testing conducted on a steam line located downstream of a separator.

Because the device can only sample saturated flows, care will have to be exercised in its application. When used to sample a very dry saturated flow, the configuration of the attachment of the device to the main line will have to be such that negligible throttling of the sample flow occurs. Sample flows obtained from steam discharge lines from separators could be superheated by the boiling point loss at separation as well as by throttling of the steam.

It could be possible to measure noncondensable gas concentrations in superheated flows by coupling the measurement device to a desuperheater.

6.0 COMMERCIALIZATION PLAN

6.1 Device Modification

During the course of the testing program, it became evident that incorporation of some instrument modifications would improve measurement accuracy and permit easier operation of the device. These recommended modifications are as follows:

- 1) Extension of the main body of the instrument to enable repositioning of the static pressure tap to directly upstream of the capsule assembly.
- 2) Dampening of the output from the differential pressure transmitters (by either mechanical or electrical means).
- 3) Addition of isolation valves to the differential pressure transmitters.

Repositioning of the static pressure tap to directly upstream of the capsule assembly would decrease the velocity dependence problems present in the current design. Presently, the static pressure tap is located in a section of 1 inch pipe located upstream of the vessel portion of the device (which is fabricated from 2 inch pipe). The improved performance would be realized from decreased sample velocities in 2 inch versus 1 inch pipe and from decrease in the pressure difference in the sample flow between the point of static pressure measurement and the location of the capsule assembly.

During testing, sample flow static pressures were found to fluctuate considerably. These fluctuations were propagated through the transmitters and thus result in considerable noise in

the recorded signal. A more interpretable signal and hence more accurate reading of noncondensable gas concentration would be obtained by dampening either the static pressure tap line or the output from the differential pressure transmitters (via an integrating circuit).

During the storage of the instrument at ambient temperature, a high vacuum exists in the capsule/pressure transmitter portion of the device. At times, this vacuum causes a drift in the calibration of the low range differential pressure transmitter, necessitating capsule venting and transmitter recalibration. The addition of isolation valves to the transmitter connection lines would correct this problem.

6.2 Further Testing

Following implementation of the outlined device modifications, additional laboratory testing of the instrument is recommended. This testing will assess the effect of the modifications upon device measurement accuracy, determine device response characteristics when exposed to sample pressure and gas concentration transients, and will assess the long term reliability of the device.

6.3 Commercialization

Following completion of device modification and testing, a brochure describing instrument design and capabilities will be prepared. This brochure will be distributed to companies and organizations involved in geothermal energy utilization. The response to this distribution will be used to assess the market potential of the device.

Upon verifying the market for the device, preparations for manufacturing will be made. The design of the device will be re-reviewed to ensure that applicable codes and standards are satisfied and that no safety concerns exist. Detailed fabrication and assembly procedures as well as associated quality assurance and quality control programs will be developed.

To ensure successful introduction of the device to the geothermal industry, it will probably be necessary to provide consulting services to the initial purchasers. On site assistance during initial startup and operation of the device would aid in training personnel to use the device and would facilitate expedient solution of any problems encountered. This close cooperation with initial purchasers would also enable compilation of a record of device operating experiences in a variety of geothermal environments.

7.0 ACKNOWLEDGEMENTS

Appreciation is expressed to Lawrence Berkeley Laboratory for providing support for the project under the Geothermal Reservoir Engineering Management Program. The technical review provided by J. H. Howard, P. Rapier, and R. Fulton of LBL throughout the project was very beneficial.

The efforts of G. D. McDowell of the New

Zealand Department of Scientific and Industrial Research were of primary importance during initial design of the device and during the field testing program. The DSIR's support of Mr. McDowell during the New Zealand field testing is appreciated.

Laboratory facilities provided by the Mechanical Engineering Department of the University of Utah were instrumental in the development of the device. The cooperation and assistance of Phillips Petroleum Company and of Union Oil Company in providing facilities for and in reviewing data from the field testing program are greatly appreciated.

8.0 REFERENCES

1. V. L. Streeter, FLUID MECHANICS, 5th ED., McGraw-Hill Book Company, New York, New York, 1971.
2. A. J. Ellis and W. A. J. Mahon, CHEMISTRY AND GEOTHERMAL SYSTEMS, Academic Press, New York, New York, 1977.

APPENDIX 1

DISCUSSION OF DEVICE ENTHALPY MEASUREMENT CAPABILITY

Configuration:

P = Pressure
T = Temperature
X = Quality
h = Enthalpy
n = Mole Fraction Noncondensable Gas to Steam

Governing Equations:

$$1. X_1 = \frac{h_1 - hf_1}{hfg_1}$$

$$2. X_2 = \frac{h_2 - hf_2}{hfg_2}$$

Assuming a constant enthalpy process:
 $h_1 = h_2$ or

$$3. hfg_1 X_1 + hf_1 = hfg_2 X_2 + hf_2$$

$$4. n_1 = \left(\frac{\text{No. Moles Gas}}{\text{No. Moles Steam}} \right)_1$$

$$5. n_2 = \left(\frac{\text{No. Moles Gas}}{\text{No. Moles Steam}} \right)_2$$

$$6. X_1 = \left(\frac{\text{No. Moles Steam}}{\text{Total Moles H}_2\text{O}} \right)_1$$

$$7. X_2 = \left(\frac{\text{No. Moles Steam}}{\text{Total Moles H}_2\text{O}} \right)_2$$

Assuming no interaction of noncondensable gases with liquid phase:

$$8. \frac{X_1}{X_2} = \frac{(\text{No. Moles Steam})_1}{(\text{No. Moles Steam})_2} = \frac{n_2}{n_1}$$

or

$$X_1 = X_2 \frac{n_2}{n_1}$$

Substituting 8) into 3) and solving for X_1 :

$$9. X_1 = \frac{hf_2 - hf_1}{hfg_1 - (hfg_2) \left(\frac{n_1}{n_2} \right)}$$

NOTE: The above analysis neglects noncondensable gas/liquid phase interactions. For increased accuracy, these interactions should be considered via use of Henry's Law for gas solubility and Raoult's Law for vapor/liquid solution equilibrium.

Instrument Accuracy

To access the accuracy of the device in measuring steam quality, the maximum error in X_1 was calculated using 9) over a range of sample pressures, line qualities, and noncondensable gas concentrations. In 9), the enthalpies were assumed to be absolute values; η_1 and η_2 were assigned uncertainties based upon device capabilities. The results are shown in the following figures.

As shown in the figures, the device can be used to measure line quality where:

- 1) Noncondensable gas concentrations are relatively high.
- 2) Line steam qualities are relatively low.
- 3) Small sample pressure/line pressure ratios are possible.

FIGURE A1-1. Maximum Steam Quality Measurement Error Vs. Nondimensionalized Sample Pressure - 0.01 Molar Ratio Noncondensables to Steam.

FIGURE A1-2. Maximum Steam Quality Measurement Error Vs. Nondimensionalized Sample Pressure - Molar Ratio Noncondensables to Steam = 0.1

APPENDIX 2
ENGINEERING DESIGN DRAWINGS

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REVISIONS			
REV.	DATE	DESCRIPTION	APPROVED
1	8/8/00	REDRAWN - AS-BUILT	CYB

26

NOTES:

1. SHIELDED ARC WELDING, E-316 FILLER
2. PIECE SHOWN 90° FROM ACTUAL POSITION

ITEM	QTY	DESCRIPTION	PART OR IDENTIFYING NO.	SPECIFICATION	MATERIAL OR NOTES
16	6	1/4"-20 UNC-2A, ALUMINUM CAP SCREW, 1" LB.		COMMERCIAL	STEEL
15	1	1/4" STEAM GASKET		COMMERCIAL	AGRES-705
14	1	300 LB. GATE VALVE, 1/4"		COMMERCIAL	316 SS
13	1	RESISTANCE TEMP. PROBE	OMEGA PR-15-2-100-1/4		
12	1	3/4" x 1/2" BUSHING		COMMERCIAL	316 SS
11	1	EXHAUST SUPPORT GASKET	400020-2		316 SS
10	1	1/2" SCH 40 PIPE, 1 END THREADED, 6" LG.		COMMERCIAL	316 SS
9	1	END BACK SUB. ASSY.	400008		316 SS
8	1	HEAT SHIELD SUB. ASSY.	400009		316 SS
7	1	BODY SUB. ASSEMBLY	400007		316 SS
6	1	INTAKE SUPPORT W/SET	400020-1		316 SS
5	1	1" SCH 40 PIPE, 1 END THREADED, 6" LG.		COMMERCIAL	316 SS
4	1	2000 LB. COUPLING - 1"		COMMERCIAL	316 SS
3	1	ISOLATION DAMPER/ARM ASSY.	400005		
2	1	STEAM PRESSURE TRANSDUCER	400025		316 SS
1	1	300 LB. GATE VALVE - 1"		COMMERCIAL	316 SS

ASSEMBLY: DASH. NO.		LIST OF MATERIALS OR PARTS LIST	
MATERIAL	APPROVED	DATE	
ENGINEER	CYB	8/8/00	
CHECKED			
HEAT TREAT			
FINISH			
UNLESS OTHERWISE SPECIFIED DIMENSIONS SHALL FOLLOW THE TOLERANCE LIMITS LISTED BELOW		TerraTek	
DIMENSIONS		GAS PROBE UNIT ASSEMBLY	
UNLESS OTHERWISE SPECIFIED DIMENSIONS SHALL FOLLOW THE TOLERANCE LIMITS LISTED BELOW		SCALE 1/2" = 1"	
UNLESS OTHERWISE SPECIFIED DIMENSIONS SHALL FOLLOW THE TOLERANCE LIMITS LISTED BELOW		REV 1	

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REVISIONS			
ZONE	LTR	DESCRIPTION	DATE

SECTION A-A

NOTES:

ITEM	QTY	NOMENCLATURE OR DESCRIPTION	PART OR IDENTIFYING NO.	SPECIFICATION	MATERIALS OR NOTES
ASSEMBLY DASH NO.		LIST OF MATERIALS OR PARTS LIST			
MATERIAL		APPROVED <i>[Signature]</i>	DATE	TerraTek GAS PROBE UNIT ASSEMBLY	
ENGINEER		C. R. Blum	11-14-78		
CHECKED					
HEAT TREAT		DRAWN <i>[Signature]</i>	11-7-78	400001	
FINISH		UNLESS OTHERWISE SPECIFIED DIMENSIONS SHALL FALL WITHIN THE TOLERANCE LIMITS LISTED BELOW			
UNLESS OTHERWISE NOTED		BASIC DIM. DECIMAL FRACTION BASIC DIM. DECIMAL FRACTION			
		UNDER 6"	± .02 ± .010 ± 1/32	UNDER 180 mm	± .02 ± .010 ± 1/32
		6" TO 24"	± .03 ± .020 ± 1/16	180-600 mm	± .03 ± .020 ± 1/16
		OVER 24"	± .06 ± .030 ± 1/8	OVER 600 mm	± .06 ± .030 ± 1/8
		ANGLES	± .030		
		SCALE	FULL	R.A.	SHEET 2 OF 2

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REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED
5-C,D	1	ADDED PORT DESIGNATION	8/18/80	C.R.B.

1. USE $\frac{1}{8}$ " STAINLESS STEEL TUBE &
SWAGELOCK STAINLESS STEEL FITTINGS
AS REQUIRED

NOTES:

3	1	PRESSURE	MATRAM 704-115	0-50 $\frac{in}{in}$ H ₂ O	—
2	1		MATRAM 704-115	0-25 $\frac{in}{in}$ H ₂ O	—
1	1	TRANSMITTERS	MATRAM 704-115	0-300 $\frac{in}{in}$ H ₂ O	—

ASSEMBLY DASH NO.	APPROVED	DATE	TerraTek TRANSDUCER HYDRAULIC CONNECTION DIAGRAM
MATERIAL	ENGINEER	11-14-78	
HEAT TREAT	CHECKED		
FINISH	DRAWN	11-7-78	
UNLESS OTHERWISE SPECIFIED DIMENSIONS SHALL FALL WITHIN THE TOLERANCE LIMITS LISTED BELOW			
BASIC DIM DECIMAL FRACTION BASIC DIM DECIMAL FRACTION UNDER 6" 1/100 1/32 UNDER 180 mm 0.10 mm 1/32 6" TO 24" 1/50 1/16 180-400 mm 0.15 mm 1/16 OVER 24" 1/25 1/8 OVER 400 mm 0.20 mm 1/8			SIZE B 400000 1
UNLESS OTHERWISE NOTED			SCALE R.A. SHEET OF

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REVISIONS			
ZONE	LTR	DESCRIPTION	DATE
			APPROVED

2. SHIELDED ARC WELDS
E-316 FILLER

NOTES: 1. BREAK ALL EDGES .005/.010 RAD. UNLESS OTHERWISE SPECIFIED

ITEM	QTY	NOMENCLATURE OR DESCRIPTION	PART OR IDENTIFYING NO.	SPECIFICATION	MATERIALS OR NOTES
4	6	CAPSULE FINIS	400013-D1	—	316 SS
3	2	CAPSULE TUBES	400011	—	316 SS
2	1	CAPSULE BODY	400010	—	316 SS
1	2	CAPSULE END PLUGS	400009	—	316 SS

ASSEMBLY DASH NO.	APPROVED	DATE	TerraTek CAPSULE SLIB-ASSEMBLY 400003 SCALE FULL R.A. SHEET 1 OF 1
MATERIAL	ENGINEER	11-14-78	
HEAT TREAT	CHECKED	11-2-78	
FINISH	DRAWN	11-2-78	
UNLESS OTHERWISE SPECIFIED DIMENSIONS SHALL FALL WITHIN THE TOLERANCE LIMITS LISTED BELOW BASIC DIM. DECIMAL TOLERANCE BASIC DIM. DECIMAL TOLERANCE UNDER .125 .005 .125 TO .500 .010 .500 TO 1.000 .015 1.000 TO 2.000 .020 2.000 TO 5.000 .030 5.000 TO 10.000 .050 10.000 TO 100.000 .100 100.000 TO 1000.000 .150 1000.000 TO 10000.000 .250			
UNLESS OTHERWISE NOTED			

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REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED
4-C	1	DELETE DIAPHRAGM, SEAL WELD VENT	8/18/80	C.R.B.

3. N.S. = NATIONAL SEMICONDUCTOR
2. SHIELDED ARC WELD
E-3/16 FILLER

NOTES: 1. BREAK ALL EDGES .005/.010 RAD. UNLESS OTHERWISE SPECIFIED

ITEM	QTY	NOMENCLATURE OR DESCRIPTION	PART OR IDENTIFYING NO	SPECIFICATION	MATERIALS OR NOTES
6	1	DIAPHRAGM	N.S. LX 14xx ORE	-	SILICONE
5	1	DIAPHRAGM BODY	400019	-	316 SS
4	1	VENT SCREW	400019	-	STEEL
3	1	DIAPHRAGM SEAL	N.S. LX 14xx ORE	-	TEFLON
2	1	DIAPHRAGM PLUG	400018	-	316 SS
1	1	CAP CONNECTOR	5mm BLOC SS-200-C	-	316 SS

ASSEMBLY DASH NO		LIST OF MATERIALS OR PARTS LIST	
MATERIAL	APPROVED <i>C.R.B.</i>	DATE	11-14-78
HEAT TREAT	ENGINEER <i>C.R.B.</i>	CHECKED	
FINISH	DRAWN <i>CBV</i>	DATE	11-14-78
UNLESS OTHERWISE SPECIFIED DIMENSIONS SHALL FALL WITHIN THE TOLERANCE LIMITS LISTED BELOW			
BASIC DIM		DIMENSIONAL TOLERANCES	
UNDER 6"		± .005	UNDER 100 mm
6" TO 24"		± .005	100-500 mm
OVER 24"		± .005	OVER 500 mm
ANGLES 90°		± .005	
SCALE		FULL	
SHEET		OF	

TerraTek

TEST CAPSULE DIAPHRAGM SUB-ASSEMBLY

400004

REV 1

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REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED
-	1	REDRAWN - REDESIGN	8/11/80	C.R.B.

NOTES: 1. BREAK ALL EDGES .005/.010 RAD. UNLESS
OTHERWISE SPECIFIED

ITEM	QTY	NOMENCLATURE OR DESCRIPTION	PART OR IDENTIFYING NO.	SPECIFICATION	MATERIALS OR NOTES
5	6	CAP SCREW	1/4-20 UNC-2A,	-	STL.
4	1	GASKET	GARLOCK 900/7735	-	ARBESTOS
3	1	DIAPHRAGM	400024-3	ASTM W40	SILICONE
2	1	HOUSING COVER	400024-2	-	316 SS
1	1	HOUSING	400024-1	-	316 SS

ASSEMBLY DASH NO.	APPROVED	DATE	TerraTek STATIC PRESSURE TAP DIAPHRAGM SUB-ASSY. B 400005
MATERIAL	ENGINEER		
CHECKED			
NEW TREAT	DRAWN UNLESS OTHERWISE SPECIFIED DIMENSIONS SHALL FALL WITHIN THE TOLERANCE LIMITS LISTED BELOW		
FINISH	BASIC DIM UNDER 6" 1/20 1/100 1/500 1/1000 6" TO 30" 1/100 1/500 1/1000 1/1000 OVER 30" 1/500 1/1000 1/1000 1/1000		SIZE 1/8" 1/4" 3/8" 1/2" 3/4" 1" 1 1/2" 2" 3" 4" 6" 8" 10" 12" 16" 20" 24" 30" 36" 48" 60" 72" 96" 120" 144" 180" 240" 300" 360" 480" 600" 720" 960" 1200"
UNLESS OTHERWISE NOTED		ANGLES 1/8"	SCALE FULL

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REVISIONS			
ZONE	LTR	DESCRIPTION	DATE
			APPROVED

2. SHIELDED ARC WELDS
E-316 FILLER

NOTES: 1. BREAK ALL EDGES .005/.010 RAD. UNLESS OTHERWISE SPECIFIED

ITEM	QTY	NOMENCLATURE OR DESCRIPTION	PART OR IDENTIFYING NO	SPECIFICATION	MATERIALS OR NOTES
4	1	LOCATING PIN	400014-02	-	316 SS
3	1	LOCATING PIN	400014-01	-	316 SS
2	1	HEAT SHIELD	400012	-	316 SS
1	6	HEAT SHIELD FINS	400013-02	-	316 SS

ASSEMBLY DASH NO	DATE	TerraTek
MATERIAL	11-14-78	
ENGINEER	11-3-78	HEAT SHIELD SUB-ASSEMBLY
CHECKED		
HEAT TREAT		REV 0
FINISH		
UNLESS OTHERWISE NOTED		SCALE 1/4" = 1"

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REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED

2 SHIELDED ARC WELDS
E-316 FILLER

NOTES: 1. BREAK ALL EDGES .005/.010 RAD. UNLESS
OTHERWISE SPECIFIED

4	1	2" CONCENTRIC RIBS	COMMERCIAL	-	316 SS
3	2	CAP	DRAGBLOK SS-4000	-	316 SS
2	1	BODY	400015	-	316 SS
1	1	FLANGE	400016	-	316 SS

ASSEMBLY DASH NO.	DATE	LIST OF MATERIALS OR PARTS LIST	
MATERIAL	APPROVED <i>[Signature]</i>	TerraTek	
HEAT TREAT	ENGINEER <i>C.K. Blass</i>	BODY SUB-ASSEMBLY	
FINISH	CHECKED <i>[Signature]</i>	DATE 11-14-78	
	DRAWN <i>EB Ward</i>	DATE 11-3-78	
	UNLESS OTHERWISE SPECIFIED DIMENSIONS SHALL FALL WITHIN THE TOLERANCE LIMITS LISTED BELOW		
	BASIC DIM	PRECISION	PRECISION
	UNDER 6"	± .005	± .010
	6" TO 24"	± .005	± .010
	OVER 24"	± .005	± .010
	ANGLES 90°	± .005	± .010
	SCALE	1" = 1"	1" = 1"
	SHEET	1	OF 1

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REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED

2. SHIELDED ARC WELDS
E-316 FILLER

NOTES: 1. BREAK ALL EDGES .005/.010 RAD. UNLESS OTHERWISE SPECIFIED

5	1	TEST CAPSULE DIA.	4000004	-	316 SS
4	1	CAPSULE SUB-ASBLY	4000003	-	316 SS
3	1	END BLOCK	4000017	-	316 SS
2	1	PLUG	SWAGelok SS-200P	-	316 SS
1	1	SHUT-OFF VALVE	WHITNEY A-OKM2-S2	-	316 SS

ASSEMBLY DASH NO.		DATE	
APPROVED <i>[Signature]</i>		11-14-78	
ENGINEER <i>[Signature]</i>			
CHECKED <i>[Signature]</i>		11-6-78	
DRAWN <i>[Signature]</i>			
UNLESS OTHERWISE SPECIFIED DIMENSIONS SHALL FALL WITHIN THE TOLERANCE LIMITS LISTED BELOW			
BASIC DIM	DECIMAL	FRACTION	ROUND
UNDER 6"	± .02	± 1/32	UNDER 150 mm
6" TO 24"	± .03	± 1/16	150-400 mm
OVER 24"	± .06	± 1/8	OVER 400 mm
ANGLES 90°		UNLESS OTHERWISE NOTED	
TERRATEK		END BLOCK SUB-ASSEMBLY	
SIZE B		4000008	
SCALE 1/4" = 1"		SHEET 1 OF 1	

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REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED

NOTES: 1. BREAK ALL EDGES .005/.010 RAD. UNLESS OTHERWISE SPECIFIED

ITEM	QTY	NOMENCLATURE OR DESCRIPTION	PART OR IDENTIFYING NO	SPECIFICATION	MATERIALS OR NOTES
LIST OF MATERIALS OR PARTS LIST					
ASSEMBLY DASH NO		DATE			
MATERIAL 316 STAINLESS STEEL		APPROVED <i>[Signature]</i>	11-14-78		
ENGINEER R. Blum		CHECKED	TerraTek		
HEAT TREAT N		DRAWN <i>[Signature]</i>	CAPSULE END PLUG		
UNLESS OTHERWISE SPECIFIED DIMENSIONS SHALL FALL WITHIN THE TOLERANCE LIMITS LISTED BELOW					
BASIC DIM		TOLERANCE		DECIMAL	
UNDER 6"		± .005		± .005	
6 TO 24"		± .010		± .010	
OVER 24"		± .020		± .020	
FINISH 32u		UNLESS OTHERWISE NOTED		SCALE FULL	
ANGLES 90°		UNLESS OTHERWISE NOTED		SHEET OF	

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REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED

NOTES: 1. BREAK ALL EDGES .005/.010 RAD. UNLESS OTHERWISE SPECIFIED

ITEM	QTY	NOMENCLATURE OR DESCRIPTION	PART OR IDENTIFYING NO	SPECIFICATION	MATERIALS OR NOTES
ASSEMBLY DASH NO					
MATERIAL		APPROVED <i>[Signature]</i> DATE <i>11-14-78</i>			
3/8" .035 WALL		ENGINEER <i>C.R. Blair</i>		TerraTek	
3/8" .316 SS TUBE		CHECKED		CAPSULE BODY	
HEAT TREAT		DRAWN <i>PEVard</i>		11-2-78	
N		UNLESS OTHERWISE SPECIFIED DIMENSIONS SHALL FALL WITHIN THE TOLERANCE LIMITS LISTED BELOW			
FINISH		BASIC DIM		TOLERANCE	
STOCK		UNDER 6"		± .010	
		6" TO 24"		± .020	
		OVER 24"		± .030	
		ANGLES DIM		± 1/8"	
		V" UNLESS OTHERWISE NOTED			
		SCALE FULL		SHEET 1 OF 1	

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REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED

NOTES: 1. BREAK ALL EDGES .005/.010 RAD. UNLESS OTHERWISE SPECIFIED

ITEM	QTY	NOMENCLATURE OR DESCRIPTION	PART OR IDENTIFYING NO	SPECIFICATION	MATERIALS OR NOTES
ASSEMBLY DASH NO					
MATERIAL .036 WALL					
APPROVED		DATE		TerraTek	
ENGINEER		11-14-78		CAPSULE TUBE	
CHECKED		11-2-78		REV	
DRAWN		11-2-78		0	
UNLESS OTHERWISE SPECIFIED DIMENSIONS SHALL FALL WITHIN THE TOLERANCES LISTED BELOW					
BASIC DIM					
FRACTIONAL					
DECIMAL					
TOLERANCE					
UNDER 1/8"					
1/8" TO 1"					
1" TO 2"					
OVER 2"					
ANGLES 90°					
UNLESS OTHERWISE NOTED					
SCALE FULL					
SHEET 1 OF 1					

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REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED

2
NOTES: 1. BREAK ALL EDGES .005/.010 RAD. UNLESS OTHERWISE SPECIFIED

ASSEMBLY DASH NO	ITEM QTY	NOMENCLATURE OR DESCRIPTION	PART OR IDENTIFYING NO	SPECIFICATION	MATERIALS OR NOTES																								
MATERIAL 1/4" 316 SS TUBE	APPROVED <i>[Signature]</i>	DATE 11-14-78	TerraTek																										
ENGINEER C. R. Blum	CHECKED PENARO	10-23-78	HEAT SHIELD																										
HEAT TREAT N	UNLESS OTHERWISE SPECIFIED DIMENSIONS SHALL FALL WITHIN THE TOLERANCE LIMITS LISTED BELOW																												
FINISH Stock	<table border="1"> <tr> <th>BASIC DIM</th><th>FRACTIONAL</th><th>DECIMAL</th><th>BASIC DIM</th><th>FRACTIONAL</th><th>DECIMAL</th></tr> <tr> <td>UNDER 8"</td><td>1/32</td><td>0.015</td><td>UNDER 100 mm</td><td>1/32</td><td>0.38 mm</td></tr> <tr> <td>8" TO 24"</td><td>1/16</td><td>0.031</td><td>100-400 mm</td><td>1/16</td><td>0.75 mm</td></tr> <tr> <td>OVER 24"</td><td>1/8</td><td>0.062</td><td>OVER 400 mm</td><td>1/8</td><td>1.50 mm</td></tr> </table>					BASIC DIM	FRACTIONAL	DECIMAL	BASIC DIM	FRACTIONAL	DECIMAL	UNDER 8"	1/32	0.015	UNDER 100 mm	1/32	0.38 mm	8" TO 24"	1/16	0.031	100-400 mm	1/16	0.75 mm	OVER 24"	1/8	0.062	OVER 400 mm	1/8	1.50 mm
BASIC DIM	FRACTIONAL	DECIMAL	BASIC DIM	FRACTIONAL	DECIMAL																								
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OVER 24"	1/8	0.062	OVER 400 mm	1/8	1.50 mm																								
UNLESS OTHERWISE NOTED		SCALE Full		SHEET 01																									

3		2		1	
REVISIONS					
ZONE	LTR	DESCRIPTION		DATE	APPROVED

PART No.	A
400013-01	0.100
400013-02	0.423

ITEM		QTY	NOMENCLATURE OR DESCRIPTION		PART OR IDENTIFYING NO	SPECIFICATION	MATERIALS OR NOTES																																																							
ASSEMBLY DASH NO			LIST OF MATERIALS OR PARTS LIST																																																											
MATERIAL	316		APPROVED	<i>SP. 1000</i>	DATE	<div style="text-align: center; font-size: 2em; font-weight: bold;">TerraTek</div> <div style="text-align: center; font-size: 1.5em; font-weight: bold;">10-82 CAPSULE & SHIELD FINS</div>																																																								
2	STAINLESS STEEL		ENGINEER	<i>R. Blum</i>	11-14-79																																																									
			CHECKED																																																											
HEAT TREAT			DRAWN	<i>EDWARD</i>																																																										
FINISH			UNLESS OTHERWISE SPECIFIED DIMENSIONS SHALL FALL WITHIN THE TOLERANCE LIMITS LISTED BELOW																																																											
	125		<table border="1"> <thead> <tr> <th colspan="2">BASIC DIM</th> <th colspan="2">TOLERANCE</th> <th colspan="2">BASIC DIM</th> <th colspan="2">TOLERANCE</th> </tr> </thead> <tbody> <tr> <td>UNDER 1"</td> <td>± .005</td> <td>1" - 2"</td> <td>± .010</td> <td>2" - 6"</td> <td>± .015</td> <td>6" - 18"</td> <td>± .020</td> </tr> <tr> <td>1" - 2"</td> <td>± .005</td> <td>2" - 6"</td> <td>± .010</td> <td>6" - 18"</td> <td>± .015</td> <td>18" - 36"</td> <td>± .020</td> </tr> <tr> <td>OVER 2"</td> <td>± .005</td> <td>2" - 6"</td> <td>± .010</td> <td>6" - 18"</td> <td>± .015</td> <td>18" - 36"</td> <td>± .020</td> </tr> </tbody> </table>		BASIC DIM		TOLERANCE		BASIC DIM		TOLERANCE		UNDER 1"	± .005	1" - 2"	± .010	2" - 6"	± .015	6" - 18"	± .020	1" - 2"	± .005	2" - 6"	± .010	6" - 18"	± .015	18" - 36"	± .020	OVER 2"	± .005	2" - 6"	± .010	6" - 18"	± .015	18" - 36"	± .020	<table border="1"> <thead> <tr> <th colspan="2">SPECIAL</th> <th colspan="2">SIZE</th> <th colspan="2">REV</th> </tr> </thead> <tbody> <tr> <td>1" - 2"</td> <td>± .005</td> <td>1" - 2"</td> <td>± .010</td> <td>1</td> <td>0</td> </tr> <tr> <td>2" - 6"</td> <td>± .010</td> <td>2" - 6"</td> <td>± .015</td> <td>2</td> <td>0</td> </tr> <tr> <td>6" - 18"</td> <td>± .015</td> <td>6" - 18"</td> <td>± .020</td> <td>3</td> <td>0</td> </tr> </tbody> </table>		SPECIAL		SIZE		REV		1" - 2"	± .005	1" - 2"	± .010	1	0	2" - 6"	± .010	2" - 6"	± .015	2	0	6" - 18"	± .015	6" - 18"	± .020	3	0
BASIC DIM		TOLERANCE		BASIC DIM		TOLERANCE																																																								
UNDER 1"	± .005	1" - 2"	± .010	2" - 6"	± .015	6" - 18"	± .020																																																							
1" - 2"	± .005	2" - 6"	± .010	6" - 18"	± .015	18" - 36"	± .020																																																							
OVER 2"	± .005	2" - 6"	± .010	6" - 18"	± .015	18" - 36"	± .020																																																							
SPECIAL		SIZE		REV																																																										
1" - 2"	± .005	1" - 2"	± .010	1	0																																																									
2" - 6"	± .010	2" - 6"	± .015	2	0																																																									
6" - 18"	± .015	6" - 18"	± .020	3	0																																																									
UNLESS OTHERWISE NOTED			SCALE		FULL	SHEET 1 OF 1																																																								

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED
C-2	A	DIMENSIONS	1-9-79	C.R. Blum

PART No.	A
400014-01	0.82
400014-02	0.95

NOTES: 1. BREAK ALL EDGES .005/.010 RAD. UNLESS OTHERWISE SPECIFIED

ITEM QTY		NOMENCLATURE OR DESCRIPTION		PART OR IDENTIFYING NO		SPECIFICATION		MATERIALS OR NOTES	
ASSEMBLY DASH NO		LIST OF MATERIALS OR PARTS LIST							
MATERIAL		APPROVED <i>[Signature]</i>		DATE		TerraTek			
316 SS		ENGINEER C.H. Blair		11-14-76					
		CHECKED							
HEAT TREAT		DRAWN R.D. Vard		11-2-78		HEAT SHIELD LOCATING PINS			
N		UNLESS OTHERWISE SPECIFIED DIMENSIONS SHALL FALL WITHIN THE TOLERANCE RANGE LISTED BELOW							
		BASIC DIM		TYPICAL		FRACTIONAL		BASIC DIM	
		UNDER 1/8"		1/8" TO 1/4"		1/4" TO 1/2"		OVER 1/2"	
FINISH		8" TO 24"		24" TO 48"		48" TO 96"		96" TO 192"	
125		OVER 24"		OVER 48"		OVER 96"		OVER 192"	
UNLESS OTHERWISE NOTED		ANGLES 90°		120°		150°		180°	
3		2		1		1		1	

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REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED

NOTES: 1. BREAK ALL EDGES .005/.010 RAD. UNLESS OTHERWISE SPECIFIED

ASSEMBLY DASH NO.	ITEM	QTY	NOMENCLATURE OR DESCRIPTION	PART OR IDENTIFYING NO.	SPECIFICATION	MATERIALS OR NOTES
MATERIAL 2" SCH 40 316 SS PIPE	APPROVED <i>[Signature]</i> ENGINEER C. R. Han	DATE 11-14-78	TerraTek			
HEAT TREAT N	CHECKED DRAWN RDY 20	10-23-78	BODY			
FINISH Stock	UNLESS OTHERWISE SPECIFIED DIMENSIONS SHALL FALL WITHIN THE TOLERANCE LIMITS LISTED BELOW					
		BASIC DIM	TOLERANCE	FRACTION	BASIC DIM	TOLERANCE
		UNDER 6"	± .02	1/16"	UNDER 100 mm	± .13 mm
		6" TO 24"	± .03	1/8"	100-400 mm	± .20 mm
		OVER 24"	± .04	3/16"	OVER 400 mm	± .25 mm
		ANGLES	± .03			
		V" UNLESS OTHERWISE NOTED				
		SCALE	FULL	RA	SHEET	OF

B 400015

REV 0

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED

ITEM QTY NOMENCLATURE OR DESCRIPTION		PART OR IDENTIFYING NO		SPECIFICATION		MATERIALS OR NOTES	
ASSEMBLY DASH NO		LIST OF MATERIALS OR PARTS LIST					
MATERIAL 316 STAINLESS STEEL		APPROVED <i>[Signature]</i>	DATE 11-14-78	TerraTek			
ENGINEER C K Blain		CHECKED					
HEAT TREAT TN		DRAWN <i>[Signature]</i>	DATE 10-20-78	FLANGE			
FINISH 125		UNLESS OTHERWISE SPECIFIED DIMENSIONS SHALL FALL WITHIN THE TOLERANCE LIMITS LISTED BELOW					
		RANGE DIM 1/16" - 1/8" BASIC DIM 1/8" - 1/4" DECIMAL 1/8" - 1/4" SIZE					
		UNDER 1/8" 1/8" - 1/4" 1/4" - 3/8" 3/8" - 1/2" 1/2" - 3/4" 3/4" - 1" 1" - 1 1/2" 1 1/2" - 2" 2" - 4" 4" - 6" 6" - 8" 8" - 12" 12" - 18" 18" - 24" 24" - 36" 36" - 48" 48" - 60" 60" - 72" 72" - 84" 84" - 96" 96" - 108" 108" - 120" 120" - 144" 144" - 168" 168" - 192" 192" - 216" 216" - 240" 240" - 264" 264" - 288" 288" - 312" 312" - 336" 336" - 360" 360" - 384" 384" - 408" 408" - 432" 432" - 456" 456" - 480" 480" - 504" 504" - 528" 528" - 552" 552" - 576" 576" - 600" 600" - 624" 624" - 648" 648" - 672" 672" - 696" 696" - 720" 720" - 744" 744" - 768" 768" - 792" 792" - 816" 816" - 840" 840" - 864" 864" - 888" 888" - 912" 912" - 936" 936" - 960" 960" - 984" 984" - 1008" 1008" - 1032" 1032" - 1056" 1056" - 1080" 1080" - 1104" 1104" - 1128" 1128" - 1152" 1152" - 1176" 1176" - 1200" 1200" - 1224" 1224" - 1248" 1248" - 1272" 1272" - 1296" 1296" - 1320" 1320" - 1344" 1344" - 1368" 1368" - 1392" 1392" - 1416" 1416" - 1440" 1440" - 1464" 1464" - 1488" 1488" - 1512" 1512" - 1536" 1536" - 1560" 1560" - 1584" 1584" - 1608" 1608" - 1632" 1632" - 1656" 1656" - 1680" 1680" - 1704" 1704" - 1728" 1728" - 1752" 1752" - 1776" 1776" - 1800" 1800" - 1824" 1824" - 1848" 1848" - 1872" 1872" - 1896" 1896" - 1920" 1920" - 1944" 1944" - 1968" 1968" - 1992" 1992" - 2016" 2016" - 2040" 2040" - 2064" 2064" - 2088" 2088" - 2112" 2112" - 2136" 2136" - 2160" 2160" - 2184" 2184" - 2208" 2208" - 2232" 2232" - 2256" 2256" - 2280" 2280" - 2304" 2304" - 2328" 2328" - 2352" 2352" - 2376" 2376" - 2400" 2400" - 2424" 2424" - 2448" 2448" - 2472" 2472" - 2496" 2496" - 2520" 2520" - 2544" 2544" - 2568" 2568" - 2592" 2592" - 2616" 2616" - 2640" 2640" - 2664" 2664" - 2688" 2688" - 2712" 2712" - 2736" 2736" - 2760" 2760" - 2784" 2784" - 2808" 2808" - 2832" 2832" - 2856" 2856" - 2880" 2880" - 2904" 2904" - 2928" 2928" - 2952" 2952" - 2976" 2976" - 3000" 3000" - 3024" 3024" - 3048" 3048" - 3072" 3072" - 3096" 3096" - 3120" 3120" - 3144" 3144" - 3168" 3168" - 3192" 3192" - 3216" 3216" - 3240" 3240" - 3264" 3264" - 3288" 3288" - 3312" 3312" - 3336" 3336" - 3360" 3360" - 3384" 3384" - 3408" 3408" - 3432" 3432" - 3456" 3456" - 3480" 3480" - 3504" 3504" - 3528" 3528" - 3552" 3552" - 3576" 3576" - 3600" 3600" - 3624" 3624" - 3648" 3648" - 3672" 3672" - 3696" 3696" - 3720" 3720" - 3744" 3744" - 3768" 3768" - 3792" 3792" - 3816" 3816" - 3840" 3840" - 3864" 3864" - 3888" 3888" - 3912" 3912" - 3936" 3936" - 3960" 3960" - 3984" 3984" - 4008" 4008" - 4032" 4032" - 4056" 4056" - 4080" 4080" - 4104" 4104" - 4128" 4128" - 4152" 4152" - 4176" 4176" - 4200" 4200" - 4224" 4224" - 4248" 4248" - 4272" 4272" - 4296" 4296" - 4320" 4320" - 4344" 4344" - 4368" 4368" - 4392" 4392" - 4416" 4416" - 4440" 4440" - 4464" 4464" - 4488" 4488" - 4512" 4512" - 4536" 4536" - 4560" 4560" - 4584" 4584" - 4608" 4608" - 4632" 4632" - 4656" 4656" - 4680" 4680" - 4704" 4704" - 4728" 4728" - 4752" 4752" - 4776" 4776" - 4800" 4800" - 4824" 4824" - 4848" 4848" - 4872" 4872" - 4896" 4896" - 4920" 4920" - 4944" 4944" - 4968" 4968" - 4992" 4992" - 5016" 5016" - 5040" 5040" - 5064" 5064" - 5088" 5088" - 5112" 5112" - 5136" 5136" - 5160" 5160" - 5184" 5184" - 5208" 5208" - 5232" 5232" - 5256" 5256" - 5280" 5280" - 5304" 5304" - 5328" 5328" - 5352" 5352" - 5376" 5376" - 5400" 5400" - 5424" 5424" - 5448" 5448" - 5472" 5472" - 5496" 5496" - 5520" 5520" - 5544" 5544" - 5568" 5568" - 5592" 5592" - 5616" 5616" - 5640" 5640" - 5664" 5664" - 5688" 5688" - 5712" 5712" - 5736" 5736" - 5760" 5760" - 5784" 5784" - 5808" 5808" - 5832" 5832" - 5856" 5856" - 5880" 5880" - 5904" 5904" - 5928" 5928" - 5952" 5952" - 5976" 5976" - 6000" 6000" - 6024" 6024" - 6048" 6048" - 6072" 6072" - 6096" 6096" - 6120" 6120" - 6144" 6144" - 6168" 6168" - 6192" 6192" - 6216" 6216" - 6240" 6240" - 6264" 6264" - 6288" 6288" - 6312" 6312" - 6336" 6336" - 6360" 6360" - 6384" 6384" - 6408" 6408" - 6432" 6432" - 6456" 6456" - 6480" 6480" - 6504" 6504" - 6528" 6528" - 6552" 6552" - 6576" 6576" - 6600" 6					

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REVISIONS			
ZONE	LTR	DESCRIPTION	DATE

SECTION A-A

NOTES: 1. BREAK ALL EDGES .005/.010 RAD. UNLESS OTHERWISE SPECIFIED.
2. SEE NOTE 2 DRAWING 400016

ITEM	QTY	NOMENCLATURE OR DESCRIPTION	PART OR IDENTIFYING NO.	SPECIFICATION	MATERIALS OR NOTES
ASSEMBLY DASH NO		LIST OF MATERIALS OR PARTS LIST			
MATERIAL	APPROVED	DATE	TerraTek END BLOCK		
ENGINEER	C.R. Chen	11-14-78			
CHECKED					
HEAT TREAT	DRAWN	10-23-78	400017		
76	UNLESS OTHERWISE SPECIFIED DIMENSIONS SHALL FALL WITHIN THE TOLERANCE LIMITS LISTED BELOW				
	BASIC DIM	DECIMAL	INCH	BASIC DIM	DECIMAL
FINISH	UNDER 6"	± .001	± 1/32	UNDER 188 mm	± .025
125	6" TO 24"	± .002	± 1/16	188-300 mm	± .030
	OVER 24"	± .003	± 1/8	OVER 300 mm	± .030
UNLESS OTHERWISE NOTED		ANGLES	± .5°	SCALE	1:1

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REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED

2.
NOTES: 1. BREAK ALL EDGES .005/.010 RAD. UNLESS
OTHERWISE SPECIFIED

ASSEMBLY DASH NO	ITEM	QTY	NOMENCLATURE OR DESCRIPTION	PART OR IDENTIFYING NO	SPECIFICATION	MATERIALS OR NOTES				
MATERIAL 316 SS	APPROVED		DATE	TerraTek DIAPHRAGM PLUG						
ENGINEER C.R. Dan	CHECKED		11-14-78							
HEAT TREAT 72	DRAWN D. Vard		02/08							
FINISH 63	UNLESS OTHERWISE SPECIFIED DIMENSIONS SHALL FALL WITHIN THE TOLERANCE LIMITS LISTED BELOW									
		BASIC DIM	DECIMAL	FRACTION	TOL	DECIMAL				
		UNDER 6"	± .02	± .010	± 1/32	UNDER 100 mm	± .005	± .005	± .005	± .005
		6" TO 24"	± .02	± .005	± 1/16	100-500 mm	± .005	± .005	± .005	± .005
		OVER 24"	± .02	± .005	± 1/8	OVER 500 mm	± .005	± .005	± .005	± .005
		ANGLES & R								
		UNLESS OTHERWISE NOTED								
		3			2			1		
		SCALE	FULL		RA			SHEET	OF	

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REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED
4,5	1	DIMENSION CHANGES	8/11/80	C.R.B.

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REVISIONS			
ZONE	LTR	DESCRIPTION	DATE
B-4	1	CHANGED DIM. A, 400020-2	12-8-78
			APPROVED C.R. Blain

31 THRU 82° C-SINK .20 DEEP
4 HOLES

PART NO.	A	B
400020-1	2.375	1.315
400020-2	2.375	1.840

- NOTES: 1. BREAK ALL EDGES .005/.010 RAD. UNLESS OTHERWISE SPECIFIED
2. SHIELDED ARC WELDS
E-316 FILLER

ASSEMBLY DASH NO.	ITEM	QTY	NOMENCLATURE OR DESCRIPTION	PART OR IDENTIFYING NO.	SPECIFICATION	MATERIALS OR NOTES
MATERIAL 1/4 PL 316SS	APPROVED		DATE			
HEAT TREAT	ENGINEER		11-14-78			TerraTek
FINISH	CHECKED					SUPPORT GUSSETS
	DRAWN		11-14-78			
	UNLESS OTHERWISE SPECIFIED DIMENSIONS SHALL FALL WITHIN THE TOLERANCE LIMITS LISTED BELOW					
	BASIC DIM	DECIMAL	FRACTION	BASIC DIM	DECIMAL	FRACTION
	UNDER 8	± .005	± .010	UNDER 100 mm	± .005	± .010
	8 TO 24	± .005	± .010	100-400 mm	± .005	± .010
	OVER 24	± .005	± .010	OVER 400 mm	± .005	± .010
	ANGLES	± .030	± .030	OVER 60°	± .030	± .030
	UNLESS OTHERWISE NOTED					
	SCALE					

REVISIONS				
ZONE	LTR	E.C. OR DESCRIPTION	DATE	APPROVED

REVISIONS				
DATE	BY	DESCRIPTION	DATE	APPROVED

1. ☐ 2. ☐ 3. ☐ 4. ☐ 5. ☐ 6. ☐ 7. ☐ 8. ☐ 9. ☐ 10. ☐ 11. ☐ 12. ☐ 13. ☐ 14. ☐ 15. ☐ 16. ☐ 17. ☐ 18. ☐ 19. ☐ 20. ☐ 21. ☐ 22. ☐ 23. ☐ 24. ☐ 25. ☐ 26. ☐ 27. ☐ 28. ☐ 29. ☐ 30. ☐ 31. ☐ 32. ☐ 33. ☐ 34. ☐ 35. ☐ 36. ☐ 37. ☐ 38. ☐ 39. ☐ 40. ☐ 41. ☐ 42. ☐ 43. ☐ 44. ☐ 45. ☐ 46. ☐ 47. ☐ 48. ☐ 49. ☐ 50. ☐ 51. ☐ 52. ☐ 53. ☐ 54. ☐ 55. ☐ 56. ☐ 57. ☐ 58. ☐ 59. ☐ 60. ☐ 61. ☐ 62. ☐ 63. ☐ 64. ☐ 65. ☐ 66. ☐ 67. ☐ 68. ☐ 69. ☐ 70. ☐ 71. ☐ 72. ☐ 73. ☐ 74. ☐ 75. ☐ 76. ☐ 77. ☐ 78. ☐ 79. ☐ 80. ☐ 81. ☐ 82. ☐ 83. ☐ 84. ☐ 85. ☐ 86. ☐ 87. ☐ 88. ☐ 89. ☐ 90. ☐ 91. ☐ 92. ☐ 93. ☐ 94. ☐ 95. ☐ 96. ☐ 97. ☐ 98. ☐ 99. ☐ 100. ☐ 101. ☐ 102. ☐ 103. ☐ 104. ☐ 105. ☐ 106. ☐ 107. ☐ 108. ☐ 109. ☐ 110. ☐ 111. ☐ 112. ☐ 113. ☐ 114. ☐ 115. ☐ 116. ☐ 117. ☐ 118. ☐ 119. ☐ 120. ☐ 121. ☐ 122. ☐ 123. ☐ 124. ☐ 125. ☐ 126. ☐ 127. ☐ 128. ☐ 129. ☐ 130. ☐ 131. ☐ 132. ☐ 133. ☐ 134. ☐ 135. ☐ 136. ☐ 137. ☐ 138. ☐ 139. ☐ 140. ☐ 141. ☐ 142. ☐ 143. ☐ 144. ☐ 145. ☐ 146. ☐ 147. ☐ 148. ☐ 149. ☐ 150. ☐ 151. ☐ 152. ☐ 153. ☐ 154. ☐ 155. ☐ 156. ☐ 157. ☐ 158. ☐ 159. ☐ 160. ☐ 161. ☐ 162. ☐ 163. ☐ 164. ☐ 165. ☐ 166. ☐ 167. ☐ 168. ☐ 169. ☐ 170. ☐ 171. ☐ 172. ☐ 173. ☐ 174. ☐ 175. ☐ 176. ☐ 177. ☐ 178. ☐ 179. ☐ 180. ☐ 181. ☐ 182. ☐ 183. ☐ 184. ☐ 185. ☐ 186. ☐ 187. ☐ 188. ☐ 189. ☐ 190. ☐ 191. ☐ 192. ☐ 193. ☐ 194. ☐ 195. ☐ 196. ☐ 197. ☐ 198. ☐ 199. ☐ 200. ☐ 201. ☐ 202. ☐ 203. ☐ 204. ☐ 205. ☐ 206. ☐ 207. ☐ 208. ☐ 209. ☐ 210. ☐ 211. ☐ 212. ☐ 213. ☐ 214. ☐ 215. ☐ 216. ☐ 217. ☐ 218. ☐ 219. ☐ 220. ☐ 221. ☐ 222. ☐ 223. ☐ 224. ☐ 225. ☐ 226. ☐ 227. ☐ 228. ☐ 229. ☐ 230. ☐ 231. ☐ 232. ☐ 233. ☐ 234. ☐ 235. ☐ 236. ☐ 237. ☐ 238. ☐ 239. ☐ 240. ☐ 241. ☐ 242. ☐ 243. ☐ 244. ☐ 245. ☐ 246. ☐ 247. ☐ 248. ☐ 249. ☐ 250. ☐ 251. ☐ 252. ☐ 253. ☐ 254. ☐ 255. ☐ 256. ☐ 257. ☐ 258. ☐ 259. ☐ 260. ☐ 261. ☐ 262. ☐ 263. ☐ 264. ☐ 265. ☐ 266. ☐ 267. ☐ 268. ☐ 269. ☐ 270. ☐ 271. ☐ 272. ☐ 273. ☐ 274. ☐ 275. ☐ 276. ☐ 277. ☐ 278. ☐ 279. ☐ 280. ☐ 281. ☐ 282. ☐ 283. ☐ 284. ☐ 285. ☐ 286. ☐ 287. ☐ 288. ☐ 289. ☐ 290. ☐ 291. ☐ 292. ☐ 293. ☐ 294. ☐ 295. ☐ 296. ☐ 297. ☐ 298. ☐ 299. ☐ 300. ☐ 301. ☐ 302. ☐ 303. ☐ 304. ☐ 305. ☐ 306. ☐ 307. ☐ 308. ☐ 309. ☐ 310. ☐ 311. ☐ 312. ☐ 313. ☐ 314. ☐ 315. ☐ 316. ☐ 317. ☐ 318. ☐ 319. ☐ 320. ☐ 321. ☐ 322. ☐ 323. ☐ 324. ☐ 325. ☐ 326. ☐ 327. ☐ 328. ☐ 329. ☐ 330. ☐ 331. ☐ 332. ☐ 333. ☐ 334. ☐ 335. ☐ 336. ☐ 337. ☐ 338. ☐ 339. ☐ 340. ☐ 341. ☐ 342. ☐ 343. ☐ 344. ☐ 345. ☐ 346. ☐ 347. ☐ 348. ☐ 349. ☐ 350. ☐ 351. ☐ 352. ☐ 353. ☐ 354. ☐ 355. ☐ 356. ☐ 357. ☐ 358. ☐ 359. ☐ 360. ☐ 361. ☐ 362. ☐ 363. ☐ 364. ☐ 365. ☐ 366. ☐ 367. ☐ 368. ☐ 369. ☐ 370. ☐ 371. ☐ 372. ☐ 373. ☐ 374. ☐ 375. ☐ 376. ☐ 377. ☐ 378. ☐ 379. ☐ 380. ☐ 381.	
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REVISIONS			
ZONE	LTR	DESCRIPTION	DATE

SECTION A-A

- SURFACE ROUGHNESS OF INTERNAL PIPE MUST BE LESS THAN 300 MICRO INCH.
- THE EDGE OF THE HOLE ON THE INSIDE OF THE PIPE MUST HAVE NO BURRS. EDGE MAY BE VERY SLIGHTLY ROUNDED.
- RADIUS 1 END OF PART 1 TO 1.32 PRIOR TO ASSEMBLY.
- SHIELDED ARC WELDS E-316 FILLER
- APPLY SERIAL NO. AND PART NO.

NOTES: 1. BREAK ALL EDGES .005/.010 RAD. UNLESS OTHERWISE SPECIFIED.

3	1	STRAIGHTENING VANE	—	316 SS
2	1	1/4" HEX COUPLING	CAJON NO. 55-4-HCG	COMM'L 316 SS
1	1	1" SCH 40 PIPE - 22' LG	—	COMM'L 316 SS

ASSEMBLY DASH NO		LIST OF MATERIALS OR PARTS LIST																			
MATERIAL	APPROVED	DATE	TerraTek STATIC PRESSURE TAP ASSEMBLY 400023																		
HEAT TREAT	ENGINEER <i>C.R. B...</i>	<i>8/1/80</i>																			
FINISH	CHECKED	DRAWN																			
UNLESS OTHERWISE SPECIFIED DIMENSIONS SHALL FALL WITHIN THE TOLERANCE LIMITS LISTED BELOW.		<table border="1"> <tr> <th>BASIC DIM</th> <th>DECIMAL</th> <th>FRACTION</th> <th>BASIC DIM</th> <th>DECIMAL</th> <th>FRACTION</th> </tr> <tr> <td>UNDER 8"</td> <td>± .02</td> <td>± 1/16</td> <td>8" TO 24"</td> <td>± .03</td> <td>± 1/32</td> </tr> <tr> <td>OVER 24"</td> <td>± .06</td> <td>± 1/16</td> <td>OVER 24"</td> <td>± .06</td> <td>± 1/16</td> </tr> </table>		BASIC DIM	DECIMAL	FRACTION	BASIC DIM	DECIMAL	FRACTION	UNDER 8"	± .02	± 1/16	8" TO 24"	± .03	± 1/32	OVER 24"	± .06	± 1/16	OVER 24"	± .06	± 1/16
BASIC DIM	DECIMAL	FRACTION	BASIC DIM	DECIMAL	FRACTION																
UNDER 8"	± .02	± 1/16	8" TO 24"	± .03	± 1/32																
OVER 24"	± .06	± 1/16	OVER 24"	± .06	± 1/16																
V- UNLESS OTHERWISE NOTED		SCALE FULL R.A. SHEET 1 OF 1																			

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REVISIONS			
ZONE	LTR	DESCRIPTION	DATE

① DIAPHRAGM HOUSING

③ DIAPHRAGM

④ GASKET

② HOUSING COVER

2. APPLY SERIAL NO. AND PART NO.
NOTES: 1. BREAK ALL EDGES .006/.010 RAD. UNLESS OTHERWISE SPECIFIED.

ITEM	QTY	NOMENCLATURE OR DESCRIPTION	PART OR IDENTIFYING NO	SPECIFICATION	MATERIALS OR NOTES
4	1	GASKET	GARLOCK NO. 900/7735	-	ASBESTOS
3	1	DIAPHRAGM	-	ASTM VMG	SILICONE RUBBER
2	1	HOUSING COVER	-	-	316 STAINLESS
1	1	DIAPHRAGM HOUSING	-	-	316 STAINLESS

ASSEMBLY DASH NO		LIST OF MATERIALS OR PARTS LIST	
MATERIAL	APPROVED	DATE	TerraTek DETAILS - STATIC PRESSURE TAP DIAPHRAGM
AS SHOWN	ENGINEER C. R. BA...	3/6/77	
CHECKED	DRAWN C. R. BA...	3/6/77	
HEAT TREAT	UNLESS OTHERWISE SPECIFIED DIMENSIONS SHALL FALL WITHIN THE TOLERANCE LIMITS LISTED BELOW		SIZE 400024 REV 0
NONE	BASIC DIM TOL. FRACTIONAL DECIMAL TOL. FRACTIONAL		
FINISH	UNDER 6" ± .001 ± .010 1/32 UNDER 180 mm ± .001 ± .010 1/32		
125	6" TO 24" ± .001 ± .002 1/16 180-400 mm ± .001 ± .002 1/16		SCALE FULL RA
UNLESS OTHERWISE NOTED		ANGLES 90°	SHEET 1 OF 1

APPENDIX 3

PRESSURE TRANSMITTER SPECIFICATIONS

Model 704

PRODUCT BULLETIN NO. 64

Output : 0-5V DC Fully Isolated
Pressure Ranges : 0-5" W.C. Differential through 0-25 PSID
Maximum Pressure Overload: 2000 PSID—Bidirectional
Supply Input Voltages : 12 & 24V DC or 115 & 230V AC
Type : 4-wire

This transmitter is designed for differential pressure applications typical for process control installations, including flow measurements with orifice plate and flow tube devices. The Model 704 can withstand bidirectional line pressure overloads up to 2000 PSID. Standard ranges are 0-5" W.C. through 0-25 PSI Differential. These units can also be operated to a 10 PSI vacuum on either or both pressure ports.

The pressure cavity will accept any fluids compatible with 316 stainless steel and Hastelloy C. Pressure flanges are zinc plated carbon steel or optionally 316 stainless. Pressure ports are 1/4" NPT on 2 1/4" centers; flange adapters are available for conversion to 1/2" NPT and center-to-center dimensions of 2" or

2 1/4". Two 1/4" NPT purging ports are provided in each pressure flange.

The Model 704 includes Viatran's exclusive field calibration system providing a standardized calibration signal at 100%, operated by a PC toggle switch. Zero and span adjustment is $\pm 25\%$ FSPR. Interchangeable electronic chassis are another feature standard to the 700 Series transmitters. 700 Series enclosures are weatherproof and have been designed to meet the requirements for Class I, Group C & D, Division 1 & 2 hazardous locations. The 24V DC input instruments have been designed for intrinsic safety.

Dimensions

Specifications

Full Scale Pressure Range (FSPR)	0-15, 20, 30, 40, 50, 75, 100, 150, 200, 250" W.C. and 0-5, 10, 15, 20 and 25 PSI differential unidirectional. PTM9 provides bidirectional calibration.	Ripple	Model 704-12: Less than $\pm 0.06\%$ FSFR Model 704-24: Less than $\pm 0.06\%$ FSFR Model 704-115: Less than $\pm 0.15\%$ FSFR Model 704-230: Less than $\pm 0.15\%$ FSFR
Differential Base Pressure	2000 PSI both ports. Base pressure effect is less than $\pm 0.75\%$ FSFR per 1000 PSI	Circuit Protection	Polarity does not affect calibration. Units operating from AC supply are fuse protected. Units operating from DC supply are protected as follows: 24 volts - above 30 volts to 50 amps at 0.02 milliseconds 12 volts - above 16 volts to 50 amps at 0.02 milliseconds
Reference Pressure Media Limitation	Not applicable. See Pressure Capsule Material	Insulation Resistance	Better than 1000 Megohms at 50V DC
Supply Voltage	Model 704-12: 12V DC $\pm 2V$ DC 4 wire Model 704-24: 24V DC $\pm 4V$ DC 4 wire Model 704-115: 105-125V 60 Hz 4 wire Model 704-230: 220-240V 50 Hz 4 wire	Proof Pressure	± 2000 PSID single ended with less than $\pm 0.25\%$ FSFR shift in calibration. PTM38 provides ± 3000 PSID optional.
Regulation	Less than $\pm 0.1\%$ over full supply voltage range	Burst Pressure	7500 PSI
Output Signal	0-5V DC. PTM10 provides 0-10V DC	Long-Term Stability	Better than $\pm 0.25\%$ FSFR over six months.
Load Impedance	1 Kiloohm minimum	Resolution	Infinite
Accuracy*	Better than $\pm 0.25\%$ FSFR of calibrated span including errors due to linearity and hysteresis.	Frequency Response	Flat to 7 Hz
Repeatability	Better than $\pm 0.1\%$ FSFR	Shock & Vibration	Less than 2.5" W.C. per G in plane normal to diaphragm. Negligible error in remaining two planes.
Combined Zero & Span Temperature Effects on Accuracy	Less than $\pm 1.0\%$ FSFR per 100° F	Housing & External Cover Material	Copper-free cast aluminum with weather and chemical resistant epoxy coating. PTM26 provides Nituff anodize for severe corrosion environment.
Combined Zero & Span Temperature Effects on Accuracy At 4:1 Ranging	Not Applicable	Pressure Capsule Material	316 and Hastelloy C stainless steel and Viton o-ring. Pressure flanges are zinc plated carbon steel. PTM15 provides 316 S.S. pressure flanges. PTM32 provides Inconel pressure flanges.
Compensated Temperature Limits**	-20 to +180° F based on actual operating temperature.	Process Pressure Port (HI)	1/2" NPT female, on 2 1/4" centers. PTM5 provides 1/4" NPT flange adapters to allow alternate spacing for 2" or 2 1/4" .
Operating Temperature Limits	-30 to +180° F	Reference Pressure Port (LO)	See Process Pressure Ports
Range Adjustment	$\pm 25\%$ FSFR screwdriver adjustable at PC board-mounted potentiometer. PTM33 provides external adjust.	Purging Port	1/4" NPT female, supplied with Cadmium plated steel or 316 stainless steel plugs as required.
Range Calibration Signal	100% calibration signals provided by maintain-contact toggle switch.	Electrical Connection	1/2" NPT female, two provided.
Range Calibration Signal Accuracy	Better than $\pm 1.0\%$ FSFR. Exact pressure to output correlation data provided on calibration data card.	Mounting	Integral mounting flange provides bulkhead mounting or adapts to Viatran 2" pipe mounting bracket Part #PTA1.
Test Output	0-5V DC	Enclosure Classification	Weatherproof enclosure designed for Class I, Group C & D, Div. 1 & 2 hazardous locations.
		Weight	Less than 12 lbs. (4.72 Kilograms)

* Best Fit Straight Line

** Measure fluid temperature in excess of the compensated temperature limits may be acceptable depending on ambient temperature conditions.

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Model 701

PRODUCT BULLETIN NO. 42

Output : 0-5V DC fully isolated
Pressure Ranges : 0-5 thru 0-15,000 PSI
Supply Input Voltages: 12 & 24V DC or 115 & 230V AC
Type : 4 wire only

This transmitter is designed for medium and high pressure ranges from 0-5 thru 0-15,000 PSI. Like other units in the 700 Series, it delivers a 0-5V DC output proportional to applied pressure. It is available with a variety of input voltage options, but all provide the 5V output signal in a four wire system. The Model 701 can be used for both gage and vacuum pressures and a special range is available for 3-15 PSI applications.

The pressure cavity is suitable for corrosive applications and will accept any fluids compatible with 17-4, 17-7 or 303 stainless steels. An all inconel pressure cavity is available as an optional

modification. Also available as an optional modification is a 1/8" NPT purging port. For out of service cleaning the pressure cavity can be completely exposed by removing the pressure cap.

The Model 701 includes the integral 100% FSPR calibration system, full scale zero control, span control sufficient to provide a $\pm 0.25\%$ ranging adjustment and other features standard to the 700 Series transmitters. 700 Series enclosures are weathertight and have been designed to meet the requirements for Class 1 Group C & D applications. 24V DC input types have been designed for intrinsic safety.

Dimensions

Specifications

Full Scale Pressure Range (FSPR)	0-5, 10, 15, 25, 50, 100, 200, 300, 500, 1000, 2000, 3000, 5000, 10,000 and 15,000 PSIG. Also, 0-5, 10 and 15 PSI vacuum and 3-15 PSIG. Gage pressure reference cavity is common with conduit connections.	Test Output	0-5V DC
Differential Base Pressure	Not Applicable.	Zero Adjustment	±25% FSFR screw driver adjustable from panel front.
Reference Pressure	Not Applicable.	Interaction Between Zero & Span	Less than ±5% over full adjustment ranges.
Media Limitation	Not Applicable.	Ripple	Model 701-12: Less than ±0.06% FSFR Model 701-24: Less than ±0.08% FSFR Model 701-115: Less than ±0.15% FSFR Model 701-230: Less than ±0.15% FSFR
Supply Voltage	Model 701-12: 12V DC ±2V DC 4 wire Model 701-24: 24V DC ±4V DC 4 wire Model 701-115: 105-125V 60 Hz 4 wire Model 701-230: 220-240V 50 Hz 4 wire	Proof Pressure	2 times FSFR
Regulation	Less than ±0.1% V change in output over supply voltage range.	Burst Pressure	5 times FSFR
Output Signal	0-5V DC fully isolated.	Long-Term Stability	Better than ±0.25% over six months.
Load Impedance	Not Applicable.	Resolution	Infinite.
Accuracy Best Fit	Better than ±0.35% of calibrated span including errors due to linearity and hysteresis.	Position Sensitivity	Mounts in any position. Effect on zero adjusted after installation.
Straight Line	Better than ±0.1% FSFR	Frequency Response	Less than 1 millisecond for 90% rise.
Repeatability	Less than ±1.5% FSFR per 100°F	Vibration Error	Less than ±0.1% FSFR per G in plane normal to diaphragm. Negligible error in remaining two planes.
Combined Zero & Span	Less than ±0.75% FSFR per 100°F	Housing & External Cover Material	Copper free cast aluminum with weather and chemical resistant epoxy coating.
Temperature Effects On Accuracy	Less than ±0.75% FSFR per 100°F	Pressure Capsule Material	303, 17-4 PH, 17-7 PH stainless steels and Buna-N o-ring. Includes materials wetted by process fluids. (See modifications)
Combined Temperature Effects For Pressure Capsule When Supplied Separately	0 to 180°F (See modifications) Based on actual operating ambient temperature of electronics chassis.	Process Pressure Port	1/2" NPT female.
Combined Temperature Effects For Electronic Chassis When Supplied Separately	-30 to +250°F (See modifications)	Reference Pressure Port	Not Applicable.
Compensated Temperature Limits	-65 to +250°F	Purging Port	Available as modification only.
Diaphragm Temperature Limits	±25% FSFR screw driver adjustable from panel front.	Electrical Conduit Connection	1/2" NPT female, two provided.
Operating Temperature Limits	100% FSFR calibration signal operated from panel front push button. Five point calibrate system optional. (See modifications)	Mounting	Integral mounting flange with three holes threaded to accept 1/4" UNC bolts. Adapts to Viatran 2" pipe mounting bracket. Part #PTA-1.
Range Adjustment	Less than ±1% Exact pressure to output correlation data provided on calibration data card shipped with unit.	Enclosure Classification	Suitable for all weather installation. Designed for Group I Class C & D hazardous locations.
Range Calibration Signal		Nameplate & Pressure Capsule ID Plate	Stainless steel permanently fastened in place.
Range Calibration Signal Accuracy		Total Circuit Capacitance	Not Applicable.
		Total Circuit Inductance	Not Applicable.
		Circuit Time Constant	Less than 4 pounds.
		Weight	Polarity does not affect calibration. Units operating from AC supply are fuse protected.
		Circuit Protection	

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APPENDIX 4

NONCONDENSABLE GAS CONCENTRATION CALCULATION PROCEDURE

Idealizing the noncondensable gas/steam mixture as a mixture of perfect gases:

$$P_t V = N_t RT$$

Where: P = Total pressure of mixture
 V_t = Volume of mixture
 N_t = No. of moles in mixture
 R = Gas constant
 T = Mixture temperature

Utilizing Dalton's rule for partial pressures:

$$P_s = N_s \frac{RT}{V}$$

$$P_g = N_g \frac{RT}{V}$$

Where subscripts denote:

s = Steam properties
 g = Noncondensable gas properties

$$\frac{P_g}{P_s} = \frac{N_g \frac{RT}{V}}{N_s \frac{RT}{V}} = \frac{N_g}{N_s} \text{ (Molar Ratio)}$$

Utilizing Amagat's rule for partial volumes:

$$V_g = \frac{N_g RT}{P}$$

$$V_s = \frac{N_s RT}{P}$$

$$\frac{V_g}{V_s} = \frac{N_g \frac{RT}{P}}{N_s \frac{RT}{P}} = \frac{N_g}{N_s} \text{ (Volume Ratio)}$$

$\frac{P_g}{P_s} = \frac{N_g}{N_s} = \frac{V_g}{V_s}$	Ratio of partial pressures equals molar and partial volume ratio
---	--

To account for non-ideal behavior of gases, the compressibility factor can be introduced to the perfect gas equation of state as follows:

$$P_t V = Z N_t RT$$

Where: Z = Compressibility factor
 Other variables as previously defined

Utilizing Dalton's Rule for partial pressures:

$$P_s = \frac{Z_s N_s RT}{V_t}$$

$$P_g = \frac{Z_g N_g RT}{V_t}$$

(subscripts as previously defined)

or:

$$\frac{P_g}{P_s} = \frac{\frac{Z_g N_g RT}{V_t}}{\frac{Z_s N_s RT}{V_t}} = \frac{Z_g N_g}{Z_s N_s}$$

or:

$$\frac{N_g}{N_s} = \left(\frac{P_g}{P_s} \right) \left(\frac{Z_s}{Z_g} \right)$$

On a molar volume basis:

$$\hat{V}_s = \frac{V_t}{N_s}$$

$$\hat{V}_g = \frac{V_t}{N_g}$$

Where: $\hat{V}_s$ = Molar volume of steam

$\hat{V}_g$ = Molar volume of gas

or:

$$\frac{\hat{V}_s}{\hat{V}_g} = \frac{\frac{V_t}{N_s}}{\frac{V_t}{N_g}} = \frac{N_g}{N_s}$$

Thus:

$$\frac{N_g}{N_s} = \left(\frac{P_g}{P_s} \right) \left(\frac{Z_s}{Z_g} \right) = \frac{\hat{V}_s}{\hat{V}_g}$$

Utilizing Amagat's rule for partial volumes:

$$V_g = \frac{Z_g N_g RT}{P_t}$$

$$V_s = \frac{Z_s N_s RT}{P_t}$$

$$\frac{V_g}{V_s} = \frac{Z_g N_g RT / P_t}{Z_s N_s RT / P_t} = \left(\frac{Z_g}{Z_s} \right) \left(\frac{N_g}{N_s} \right)$$

If the molar weights of the constituents are known, then:

$$\frac{N_g}{N_s} \times \frac{\hat{M}_g}{\hat{M}_s} = \frac{W_g}{W_s}$$

Where: $\hat{M}$ = Molar weight of component

W = Mass of component

Subscripts as previously defined

Using the device:

P_g = Output from 0-50 in. H₂O or 0-25 psid differential pressure transmitter

P_s = Output from 0-300 psia absolute pressure transmitter

Calibration Constants:

0-50 in. H₂O unit - 9.99 $\frac{\text{in. H}_2\text{O}}{\text{VDC}}$
 (Low and high range calibration)

$$0-25 \text{ psid unit} - 5.03 \frac{\text{PSID}}{\text{VDC}}$$

(Low range calibration)

$$- 5.00 \frac{\text{PSID}}{\text{VDC}}$$

(High range calibration)

$$0-300 \text{ psia unit} - 59.67 \frac{\text{PSI}}{\text{VDC}}$$

(Low range calibration)

$$- 60.00 \frac{\text{PSI}}{\text{VDC}}$$

(High range calibration)

APPENDIX 5

MECHANICAL DESIGN CALCULATIONS

Gas Probe Stress Calculations

Capsule Collapsing Pressure

$$P = 86,670 \frac{t}{D} - 1386 \text{ (Machinery's Handbook, pg. 448)}$$

Where: P = External collapsing pressure (psi)
t = Wall thickness (in)
D = Outside Diameter (in)

For 3/8" OD. x .035 wall tube

$$P = 86,670 \left(\frac{.035}{.375} \right) - 1386 = \boxed{6703 \text{ psi}}$$

∴ Capsule will not collapse at startup

1/8" OD Tube Collapsing Pressure

$$P = 86,670 \left(\frac{.035}{.125} \right) - 1386 = \boxed{22,882 \text{ psi}}$$

∴ Tube will not collapse at startup

Diaphragm at Vacuum

Thread - Stress Area = .458 in²/in

$$\text{Force} = 14.7 \text{ psi} \times \frac{\pi (.5 \text{ in})^2}{4} = 3 \text{ lb.}$$

$$\tau = \frac{3 \text{ lb.}}{.458 \text{ in}^2/\text{in} \times .5 \text{ in}} = 10 \text{ w}$$

$$\tau = 117 \text{ psi @ P=300 psi}$$

Weld on Swagelok Connector:

$$\tau = \frac{(14.7 \text{ psi}) \pi (.75") (.125")}{(.707) \pi (.75") (.125)} = 10 \text{ w}$$

$$\tau = 20 \text{ psi @ P=300 psi}$$

Diaphragm will withstand vacuum

Allowable Threaded Pipe Pressure

$$t_m = \frac{PD}{2(SE + Py)} + A \text{ (Marks Handbook, 8th Ed., pg. 8-149)}$$

Where: t_m = Minimum pipe wall thickness, in.
P = Maximum internal pressure, psi
SE = Maximum allowable stress, psi
D = OD of pipe, in.
y = Temperature coefficient
A = Allowance for threading

Solving for P:

$$P = \frac{2(t_m - A)SE}{1 - (y)\left(\frac{2}{D}\right)(t_m - A)}$$

$$SE = 16,300 \text{ psi} \quad y = 0.4$$

Pipe Size	A	Pallow
1/2" sch. 40	.05714	2117 psi
1" sch. 40	.06957	1635 psi
2" sch. 40	.06957	1194 psi

Flange and End Block

Force exerted on connection =

$$300 \text{ psi} \times \frac{\pi (2.38 \text{ in})^2}{4} = 1334 \text{ lbs.}$$

Stress in Cap Screws -

$$\sigma = \frac{1334 \text{ lbs.}}{6(0.0269 \text{ in}^2)} = 8,270 \text{ psi} - \text{assuming no preload}$$

Assuming y.p. = 30,000 psi

$$\text{F.S.} = \frac{30,000}{8,270} = 3.63$$

Shear in Flange -

$$\tau = \frac{1334 \text{ lbs.}}{(.5")(\pi)(2.38")} = 357 \text{ psi} \Rightarrow \text{F.S. High}$$

Shear in Flange Weld -

$$\tau = \frac{1334 \text{ lbs.}}{(2)(.707)(1/8")(\pi)(2.38")} = 1000 \text{ psi} \Rightarrow \text{F. S. High}$$

Bending in Flange -

$$M = 1334 \text{ lbs.} \times .36" = 480 \text{ in-lbs}$$

$$\sigma = \frac{MC}{I} = \frac{(480 \text{ in-lbs})(.25 \text{ in})}{\frac{(\pi)(2.38")^4}{12}} = 6.88 \text{ psi} \Rightarrow \text{F.S. High}$$

Static Pressure Tap Diaphragm Assembly

Cover:

$$\sigma_{\max} = \frac{3qa^2}{4h^2} \text{ (Spotts, Design of Machine Elements, Eq. 12-68)}$$

$$q = 300 \text{ psi}$$

$$a = \frac{1.13}{2} \text{ in.}$$

$$h = .5"$$

$$\sigma = \frac{(3)(300 \text{ lb/in}^2)(\frac{1.13}{2} \text{ in})^2}{(4)(0.5 \text{ in})^2} = 287 \text{ psi (F.S. High)}$$

Body:

From Spotts (Eq. 12-4, 12-5)

$$S_r \max = \bar{P} = 300 \text{ psi (F.S. High)}$$

$$S_t \max = \frac{a^2 P}{b^2 - a^2} \left(1 + \frac{b^2}{a^2}\right)$$

$$b = \frac{2.67}{2} = 1.32$$

$$a = \frac{1.13}{2} = .57$$

$$S_t \max = \frac{(.57)^2 (300)}{1.32^2 - .57^2} \left(1 + \frac{1.32^2}{.57^2}\right) = 437 \text{ psi (F.S. High)}$$

Cap Screws

$$F = 300 \text{ psi} \times \frac{\pi(1.13)^2}{4} = 300.86 \text{ lbs.}$$

$$\sigma = \frac{300.86 \text{ lb.}}{(6)(.0269 \text{ in}^2)} = 1864 \text{ psi F.S. High}$$

APPENDIX 6

HEAT LOSS EFFECTS

Heat Transfer Scoping Calculations - Gas Concentration Measurement Device

General Configuration (Test Section):

Problem 1 - Calculate internal vessel shell temperature as a function of outer insulation thickness

Formulation:

$$q = \frac{T_0 - T_\infty}{\frac{1}{2\pi r_1 l h_i} + \frac{\ln(r_2/r_1)}{2\pi K_1 l} + \frac{\ln(r_3/r_2)}{2\pi K_2 l} + \frac{1}{2\pi r_3 l h_o}}$$

Where: T_0 = Steam temperature

T_∞ = Ambient temperature

l = Length of vessel

K_1 = Thermal conductivity of vessel

K_2 = Thermal conductivity of insulation

h_i = Inner heat transfer coefficient

h_o = Outer heat transfer coefficient

Assume: $h_o = 5 \text{ BTU/hrft}^2\text{°F}$

$K_2 = 0.030 \text{ BTU/hrft}^2\text{°F (Rockwool @200°F)}$

Saturated vapor steam

Parameters: $r_1 = 1.034"$ Steam Temp. = 400°F

$r_2 = 1.188"$

$l = 10"$

$K_1 = 10.2 \text{ BTU/hrft}^2\text{°F (304 SS@400°F)}$

Steam Velocity = 100 ft/sec

Determination of inside heat transfer coefficient (h_i):

$$Re_D = \frac{VD\rho}{\mu} \quad \rho = \frac{1}{1.8633 \frac{\text{ft}^3}{\text{lbm}}} = 0.537 \text{ lbm/ft}^3$$

$$\mu = 1.130 \times 10^{-5} \text{ lbm/ft sec}$$

$$Re_D = \frac{(100 \text{ ft/sec}) \left(\frac{2.068}{12} \text{ ft}\right) (0.537 \text{ lbm/ft}^3)}{(1.130 \times 10^{-5} \text{ lbm/ft sec})}$$

$$= 8.190 \times 10^5$$

$$St Pr^{2/3} = 0.023 Re^{-.2} \text{ (Ref. 1, Eq. 8-18)}$$

$$St = \frac{Nu}{Re Pr}$$

$$\frac{Nu}{Re Pr} (Pr^{2/3}) = 0.023 Re^{-.2}$$

$$Nu = 0.023 (Re)^{.8} (Pr)^{1/3}$$

$$Nu = (0.023) (8.190 \times 10^5)^{.8} (.94)^{1/3} = 1211.71$$

$$Nu_D = \frac{\bar{h}cD}{Kf} \quad \bar{h}c = \frac{Nu Kf}{D}$$

$$\bar{h}c = \frac{(1211.71) (0.020 \text{ BTU/hrft}^2\text{°F})}{(2.068/12 \text{ ft})}$$

$$= 140.62 \text{ BTU/hrft}^2\text{°F}$$

Solve for q for various values of r_3 :

$$q = \frac{400^\circ\text{F} - 70^\circ\text{F}}{\frac{1}{2\pi \left(\frac{1.034}{12} \text{ ft}\right) \left(140.62 \frac{\text{BTU}}{\text{hrft}^2\text{°F}}\right)} + \frac{\ln\left(\frac{1.188}{1.034}\right)}{2\pi \left(10.2 \frac{\text{BTU}}{\text{hrft}^2\text{°F}}\right) \left(\frac{10}{12} \text{ ft}\right)} + \frac{\ln(r_3/0.594)}{2\pi (0.030 \text{ BTU/hrft}^2\text{°F}) (0.5 \text{ ft})} + \frac{1}{2\pi r_3 \left(\frac{10}{12} \text{ ft}\right) (5 \text{ BTU/hrft}^2\text{°F})}}$$

$$= \frac{330^\circ\text{F}}{.0158 \frac{\text{hr}^\circ\text{F}}{\text{BTU}} + 2.60 \times 10^{-3} \frac{\text{hr}^\circ\text{F}}{\text{BTU}} + \frac{\ln(r_3/0.594)}{(0.094 \text{ BTU/hr}^\circ\text{F})}}$$

$q(\text{BTU/hr})$	$r_3(\text{in})$	Insulation Thickness (in.)
44.45	1.188	0
23.73	2.188	1
18.43	3.188	2
15.86	4.188	3
14.30	5.188	4
13.22	6.188	5
12.43	7.188	6
11.81	8.188	7

Problem 2 - Calculate the temperature of the test capsule.

Convective heat transfer coefficient on the outside of test capsule:

$$\bar{Nu}_L = \frac{\bar{h}cL}{K} = 0.036 Pr^{1/3} Re_L^{.8}$$

(Ref.1, Eq. 6-67, based on plate of length L)

$$= (0.036)(0.94)^{1/3} \left(\frac{(100 \text{ ft/sec}) \left(.537 \frac{\text{lbm}}{\text{ft}^3} \right) \left(\frac{3.5}{12} \text{ ft} \right)}{1.130 \times 10^{-5} \text{ lbm/ftsec}} \right)^{.8}$$

$$= 2889$$

$$\bar{h}c = \frac{(2889) \left(0.020 \frac{\text{BTU}}{\text{hrft}^2\text{°F}} \right)}{\left(\frac{3.5}{12} \text{ ft} \right)} = 198 \frac{\text{BTU}}{\text{hrft}^2}$$

Assumption: The inner surface of the shell is considered to be a black body (conservative).

Taking an Energy Balance on the Test Capsule:

q conv, in + qrad, out

Solve for inside surface temp:

$$q = \frac{T_o - T_{\text{surface}}}{\frac{1}{2\pi r_1 \ell h_i}}$$

$$T_o - T_{\text{surface}} = \left(\frac{q}{2\pi r_1 \ell h_i} \right) \Rightarrow T_{\text{surface}}$$

$$= 400^\circ\text{F} - \frac{q}{2\pi \left(\frac{1.034}{12} \text{ ft} \right) \left(\frac{10}{12} \text{ ft} \right) (140.62 \text{ BTU/hr ft}^2\text{°F.})}$$

$T_{\text{surface}} (^\circ\text{F})$	$r_3 (\text{in})$	$\Delta T \text{ Steam-surface } (^\circ\text{F})$
399.30	1.188	0.70
399.63	2.188	0.37
399.71	3.188	0.29
399.75	4.188	0.25
399.77	5.188	0.23
399.79	6.188	0.21
399.80	7.188	0.20
399.81	8.188	0.19

$$h_c A_t (T_{\text{steam}} - T_{\text{capsule}}) = \epsilon \sigma (T_{\text{capsule}}^4 - T_{\text{Shell}}^4)$$

$$A_t = (\pi) \left(\frac{.375}{12} \text{ ft} \right) \left(\frac{3.5}{12} \text{ ft} \right) + 2\pi \left(\frac{.375}{12} \text{ ft} \right)^2$$

$$= 0.030 \text{ ft}^2$$

$$\epsilon \text{ Stainless @ } 500^\circ\text{F.} = 0.80$$

$T_{\text{Shell}} = 399.79^\circ$ (using 5" of insulation)
Solve by Trial and Error for T_{capsule}

Tcapsule	$h_c A_T (T_{\text{steam}} - T_{\text{capsule}})$	$\epsilon \sigma (T_{\text{capsule}}^4 - T_{\text{shell}}^4)$
399.85	0.89	0.209
399.90	0.594	0.384
399.92	0.475	0.453
399.93	0.416	0.488

$T_{\text{capsule}} \approx 399.92^\circ\text{F}$.

Find corresponding error in gas concentration measurement:

$$P_G V = N_G R T \quad P_S V = N_S R T$$

$$\frac{N_G}{N_S} = \frac{P_G}{P_S} \left(\frac{\text{Mole Gas}}{\text{Mole Steam}} \right) \quad P_G = P_T - P_S$$

Assuming the Gas To Be Primarily CO₂

$$\frac{1 \text{ lbm gas}}{1 \text{ lbm steam}} = \left(\frac{P_G}{P_S} \right) \left(\frac{\text{Mole gas}}{\text{Mole Steam}} \right) \quad \left(\frac{44.01 \text{ lbm gas}}{1 \text{ lbmole gas}} \right)$$

$$\left(\frac{1 \text{ lbmole Steam}}{18.016 \text{ lbm Steam}} \right)$$

Saturation Pressures:

$$P_S 400^\circ\text{F} = 247.1 \text{ psi}$$

$$P_S 399.92^\circ\text{F} = 246.80 \text{ psi}$$

For 10% Gas Concentration

$$\frac{1 \text{ lb gas}}{1 \text{ lb steam}} = \left(\frac{P_T - P_S}{P_S} \right) \left(\frac{44.01}{18.016} \right) \quad P_T = 257.22$$

$$\text{Error} = \left| \frac{\left(\frac{257.22 - 246.88}{246.88} \right) \left(\frac{44.01}{18.016} \right) - 1}{.1} \right| \times 100\%$$

$$= 2.27\%$$

For .1% Gas Concentration:

$$.001 = \left(\frac{P_T - P_S}{P_S} \right) \left(\frac{44.01}{18.016} \right) \quad P_T = 247.201$$

$$\text{Error} = \left| \frac{\left(\frac{247.201 - 246.88}{246.88} \right) \left(\frac{44.01}{18.016} \right) - 1}{.001} \right| \times 100\%$$

$$= 218\%$$

Try A Heat Shield To Increase Capsule Temperature

Configuration:

ASSUMPTIONS:

- 1) Shield is a Perfect Absorber Of Radiation From The Capsule.
- 2) Shell is a Perfect Absorber of Radiation From The Shield.
- 3) Effect of Gases Upon Radiation is Neglected.

Note: All of these assumptions yield a conservatively low value of the capsule temperature.

Heat Balance On Shield:

$$2 h_c A_s (T_{\text{steam}} - T_{\text{shield}}) + \epsilon \sigma (T_{\text{capsule}}^4 - T_{\text{shield}}^4) = \epsilon \sigma (T_{\text{shield}}^4 - T_{\text{shell}}^4)$$

Heat Balance On Capsule:

$$h_c A_c (T_{\text{steam}} - T_{\text{capsule}}) = \epsilon \sigma (T_{\text{capsule}}^4 - T_{\text{shield}}^4)$$

Parameters:

$$h_c = 198 \text{ BTU/hr ft}^2 (\text{Previous Calc})$$

$$A_s = \pi \frac{(5.75") (1.25")}{144 \text{ in}^2/\text{ft}^2} = 0.157 \text{ Ft}^2$$

$$\epsilon = 0.8 \quad (\text{unpolished, } T=500^\circ\text{F})$$

$$T_{\text{shell}} = 399.79$$

$$A_v = 0.030 \text{ ft}^2$$

Solution Technique:

- 1) Assume Capsule Temp.
- 2) Calculate Shield Temp. From Capsule Heat Balance.
- 3) Check Shield Heat Balance
- 4) Iterate As Required

From Capsule Heat Balance:

$$T_{\text{shield}}^4 = T_{\text{capsule}}^4 - \frac{h_c A_v (T_{\text{steam}} - T_{\text{capsule}})}{\epsilon \sigma}$$

$$= T_{\text{capsule}}^4 - 4.332 \times 10^9 (T_{\text{steam}} - T_{\text{capsule}})$$

Heat Balance On Shield:

$$62.172 (T_{\text{steam}} - T_{\text{shield}}) + 1.3712 \times 10^{-9} (T_{\text{capsule}}^4 - T_{\text{shield}}^4) = 1.3712 \times 10^{-9} (T_{\text{shield}}^4 - T_{\text{shell}}^4)$$

Tcapsule	Tshield	Left Side Shield Heat Balance	Right Side Shield Heat Balance
399.95	399.86	8.700	0.261
399.99	399.97	1.740	0.638

Conclusion: Capsule temperature is 399.99⁺. Further calculation is meaningless due to accuracy considerations. The shield is effective in keeping the capsule at essentially the same temperature as the steam flow.

Reference: F. Kreith, Principles of Heat Transfer, 2nd Ed., International Textbook Co., 1965.

APPENDIX 7

THEORETICAL NONCONDENSABLE GAS CONCENTRATION MEASUREMENT ERROR

Accuracy check - Transmitters

$$P_G V = N_G RT \quad P_S V = N_S RT$$

$$\frac{N_G}{N_S} = \frac{P}{P_S} \left(\frac{\text{Mole gas}}{\text{Mole steam}} \right)$$

Assuming gas is primarily CO₂

$$\frac{\text{lbm gas}}{\text{lbm steam}} =$$

$$\left(\frac{\text{Mole gas}}{\text{Mole steam}} \right) \left(44.01 \frac{\text{lbm gas}}{\text{lbmole gas}} \right) \left(\frac{1 \text{ lbmole steam}}{18.016 \text{ lbm steam}} \right)$$

Transmitter Accuracies:

Viatran 0-25 psi (Differential): 0.25% Full Scale

1/4 span - 0 - 6.25 psi → ± 0.0156 psi

Full span - 0 - 25 psi → ± 0.0625 psi

Viatran 0-50in H₂O (Differential): 0.25% Full Scale

1/4 span - 0-12.5in H₂O(0-.451 psi) → ± 1.128x10⁻³ psi

Full span - 0-50in H₂O(0-1.806 psi) → ± 4.514x10⁻³ psi

Viatran 0-300 psi (Absolute): 0.25% Full Scale

1/4 span - 0-75 psi → ± 0.1875 psi

Full span - 0-300 → ± 0.75 psi

Using 1 0-25 psi Differential Unit and 1 0-300 psi absolute:

Steam Saturation Press. (Ps, PSIA)	Max. Error in Gas Percent Measurement (by Weight)		
	@ .1%	@ 1%	@ 20%
290	13.4%	1.5%	0.5%
145	26.9%	3.2%	1.0%
72.5	52.96%	5.5%	0.5%
36	106.93%	11.2%	1.1%
20	193.3%	20.2%	1.9%

Using 2 Differential(Ranges 0-50in H₂O and 0-25psi) and one 0-300psi absolute transmitters:

Steam Saturation Press. (Ps, PSI)	Maximum Error in Gas Percent Measurement (by Weight)				
	@ .1%	@ 1%	@ 5%	@ 10%	@ 20%
290	1.2%	0.6%	0.5%	0.8%	0.5%
145	2.4%	1.3%	1.0%	0.8%	1.0%
72.5	4.1%	0.6%	0.6%	0.8%	0.5%
36	8.2%	1.3%	1.1%	0.8%	1.1%
20	14.9%	2.3%	1.2%	1.5%	1.2%

NOTE: Transmitters are assumed to be used at full scale or 1/4 scale only.

FIGURE A7-1. Measurement Accuracies Using One 0-25 psi Viatran Differential Transmitter

FIGURE A7-2. Measurement Accuracies Using Two Viatran Differential Transmitters (0.50 in. H₂O, 0.25 psi.)

APPENDIX 8

BOILING POINT ELEVATION EFFECTS

Effect of Dissolved Salts upon Gas Concentration Measurement Accuracy

Assuming gas is primarily CO₂ - Measured gas

$$\text{concentration} \left(\frac{\text{lbm gas}}{\text{lbm steam}} \right) = \left(\frac{P_{\text{total}} - P_{\text{sat}}}{P_{\text{satH}_2\text{O}}} \right) \text{H}_2\text{O}$$

$$(44.01 \frac{\text{lbm gas}}{\text{lbmole gas}}) \left(\frac{1 \text{ lbmole steam}}{18.016 \text{ lbm steam}} \right)$$

Error Calculation Procedure -

1. For a given gas concentration and flow temperature, calculate P_{total}.
2. For a given brine concentration, determine the saturation pressure at the flow temperature.
3. Calculate the measured gas concentration and the resulting measurement error.

Brine Properties -

J.L. Haas, Jr. has developed an empirical formula based on a reference substance technique which indicates the relationship between brine saturation temperature and pure H₂O saturation temperature (at the same pressure).

(Ref: Haas, J.L. Jr., Physical Properties Of The Coexisting Phases and Thermochemical Properties of The H₂O Component In Boiling NaCl Solutions, Geological Survey Bulletin 1421-A, U.S. Government Printing Office, 1976.)

This relation is:

$$\ln T_o = (a + bT_x)^{-1} \ln T_x$$

Where: T_x = Brine Temperature (°K)

T_o = Corresponding pure water temp. (°K)

a, b = Concentration dependent polynomials

$$a = 1.0 + (5.93582 \times 10^{-6})x + (-5.19386 \times 10^{-5})x^2 + (1.23156 \times 10^{-5})x^3$$

$$b = 0.0 + (1.15420 \times 10^{-6})x + (1.41254 \times 10^{-7})x^2 + (-1.92476 \times 10^{-8})x^3 + (-1.70717 \times 10^{-9})x^4 + (1.05390 \times 10^{-10})x^5$$

Where: x is the molal concentration of NaCl in water (mole NaCl/KgH₂O)

At 400° F Brine Temp (T_x):

NaCl Molality	NaCl Weight Concentration	a	b	To(°F)
1.711x10 ⁻²	0.1%	1.000	1.979x10 ⁻⁸	399.95
0.0855	0.5%	1.000	9.970x10 ⁻⁸	399.75
0.1711	1.0%	1.000	2.015x10 ⁻⁷	399.49
0.855	5.0%	1.000	1.077x10 ⁻⁶	397.28
1.711	10.0%	1.000	2.279x10 ⁻⁶	394.25
3.421	20.0%	1.000	4.647x10 ⁻⁶	388.34

TABLE A8-1. Gas Concentration Measurement Error Versus Weight Percent Dissolved Salt (High Salt Concentrations)

Brine Concentration (WT.%)	Gas Concentration (WT.%)	Flow Temperature (°F)	PsatH ₂ O at Flow Temperature (PSI)	PsatBrine at Flow Temperature (PSI)	TH ₂ O at PsatBrine (°F)	Indicated Concentration (WT.%)	Error (%)
5.0	0.1	400°F	247.1	397.28	239.52	7.83	7,734
	1.0					8.76	776.3
	10.0					18.05	80.5
	20.0					28.36	41.8
10.0	0.1	400°F	247.1	394.25	321.28	16.82	16,720
	1.0					17.78	1,678
	10.0					27.39	174
	20.0					38.08	90.4
20.0	0.1	400°F	247.1	388.34	215.93	35.38	35,280
	1.0					36.41	3,541
	10.0					46.71	367
	20.0					58.15	190.76

TABLE A8-2. Gas Concentration Measurement Error Versus Weight Percent Dissolved Salt (Low Salt Concentrations)

Brine Concentration (WT.%)	Gas Concentration (WT.%)	Flow Temperature (°F)	PsatH ₂ O at Flow Temperature (PSI)	PsatBrine at Flow Temperature (PSI)	TH ₂ O at PsatBrine (°F)	Indicated Concentration (WT.%)	Error (%)
0.1	0.1	400°F	247.1	246.96	399.95	0.239	139.0
	1.0					1.14	14.0
	10.0					10.14	1.4
	20.0					20.15	0.75
0.5	0.1	400°F	247.1	246.40	399.75	0.79	690.0
	1.0					1.70	69.7
	10.0					10.72	7.2
	20.0					20.75	3.75
1.0	0.1	400°F	247.1	245.67	399.49	1.52	1422.6
	1.0					2.42	142.8
	10.0					11.5	15.0
	20.0					21.5	7.7

FIGURE A8-1. Gas Concentration Measurement Error versus Weight Percent Dissolved Salt (Low Concentrations)

FIGURE A8-2. Gas Concentration Measurement Error versus Weight Percent Dissolved Salt (High Concentrations)

APPENDIX 9

SAMPLE VELOCITY EFFECTS

Static Pressure/Velocity Dependence Problem

Error typically $\propto \text{const.} \times V^2$ (Ref. Streeter)

Present error as:

Range of Velocities

AtPr = 310 psi, $\dot{M}$ choked = 1.677 lbm/sec
(Ref: Design Report)

$$V_{\text{pipe}} = \frac{\dot{M}}{\rho A} = \frac{1.677 \text{ lbm/sec}}{(.6688 \text{ lbm/ft}^3)(.00600 \text{ ft}^2)} = 417.9 \text{ ft/sec}$$

AtPr = 27 psi, $\dot{M}$ choked = .1317 lbm/sec

$$V_{\text{pipe}} = \frac{\dot{M}}{\rho A} = \frac{.1317}{(.0659)(.006)} = 333.1 \text{ ft/sec}$$

As tested:

$$\begin{aligned} \dot{M} &= .152 \text{ lbm/sec} \\ P &\approx 48 \text{ psia} \Rightarrow \rho = .1130 \\ V &= \frac{.152}{(.1130)(.006)} = 224.2 \text{ ft/sec} \end{aligned}$$

Only average velocity has been measured, instantaneous velocities must be inferred from pressure measurement.

$$\Delta P = \rho \Delta h = \rho f \frac{L}{D} \frac{V^2}{2g} = \rho(\text{const}) V^2$$

$$V_{\text{ave}} = 224.2 \text{ ft/sec}$$

$$\Delta P_{\text{ave}} = 48.6 \text{ psi} - 12.5 \text{ psi} = 36.1 \text{ psi}$$

$$\rho_{\text{ave}} = .1143 \text{ lbm/ft}^3$$

$$\begin{aligned} \Rightarrow \text{const.} &= \left(\frac{\Delta P_{\text{ave}}}{\rho} \right) \left(\frac{1}{V^2} \right) = \left(\frac{36.1}{.1143} \right) \left(\frac{1}{(224.2)^2} \right) \\ &= 6.28 \times 10^{-3} \end{aligned}$$

TABLE A9-1. Measured Static Pressure Error versus Velocity

From 6/19/79 Data:

Error (in. H ₂ O)	P (PSI)	ρ (lbm/ft ³)	V^2 (ft ² /sec ²)	V (ft/sec)
.17	49.02	.1152	50,453.17	224.62
-.97	48.41	.1138	50,220.77	224.10
-4.70	48.23	.1135	50,101.11	223.83
-1.47	45.29	.1070	48,771.70	220.84
+4.30	51.02	.1197	51,215.61	226.31
2.00	51.79	.1213	51,550.33	227.05
-2.10	47.61	.1121	49,846.59	223.26
-.30	47.55	.1120	49,805.84	223.17
+.40	48.63	.1143	50,307.41	224.29
+.80	48.87	.1149	50,377.14	224.45
-.80	48.16	.1133	50,091.23	223.81
+.60	48.45	.1140	50,188.51	224.03
+.70	48.81	.1148	50,691.09	225.15
-.72	48.75	.1146	50,342.37	224.37
-1.30	45.17	.1067	48,729.84	220.75
+.80	47.14	.1111	49,621.98	222.76
+6.10	42.51	.1008	47,382.25	217.67
3.50	51.61	.1209	51,483.90	226.90
.90	50.12	.1177	50,868.90	225.54
-9.29	48.87	.1149	50,377.14	224.45
-3.79	47.55	.1120	49,805.84	223.17
-.90	47.44	.1117	49,782.87	223.12

FIGURE A9-1. Static Pressure Measurement Error Versus Velocity Squared in pressure Tap Assembly.

From Figure A9-1, the slope = 10 in. H₂O/4500 ft² SEC² which yields the following over the velocity range of the instrument (for transmitters zeroed at test condition).

FIGURE A9-2. Static Pressure Measurement Error Over Range of Operating Velocities.

Gas Concentration Measurement Error vs. Velocity

$$\frac{\text{LBM GAS}}{\text{LBM STEAM}} = \frac{P_G(44.01)}{P_S(18.016)}$$

$$V^2 = 100,000 \text{ FT}^2/\text{SEC}^2 \Rightarrow \Delta \text{Perror} = 4.012 \text{ psi (Figure A8-2)}$$

Steam Saturation Press. (PSI)	Error in Gas Concentration Measurement		
	@ 1% GAS	@ 10% GAS	@ 20% GAS
290	338.0%	33.8%	16.9%
100	980.1%	98.0%	49.0%
50	1960.1%	196.0%	98.0%

Gas Concentration Measurement Errors At Low Velocities

Per Figure A9-1, the error in static pressure measurement with velocity is approximately $0.002 \text{ in. H}_2\text{O}/(V)^2$ (zeroed at any point).

If the differential pressure transmitters are zeroed at no velocity, the static pressure measurement error vs. velocity is:

Velocity in 1" Pipe (FT/SEC)	Static Pressure Meas. Error	
	(in. H ₂ O)	(PSI)
0	0	0
10	.2	.0072
20	.8	.029
30	1.8	.065
40	3.2	.116
50	5.0	.181
60	7.2	.260
70	9.8	.354
80	12.8	.462

Gas concentration measurement error:

$$\left| \frac{\eta_{\text{meas.}}}{\eta_{\text{act.}}} - 1 \right| \times 100\%$$

$$\eta = \frac{P_G(44.01)}{P_S(18.016)} \quad (\text{Weight percent assuming gas to be CO}_2)$$

For $V = 0$, error = 0

Velocity (Ft/SEC)	Steam Sat. Pres. (PSIA)	% Error in Gas Concentration Measurement		
		@ 1.0	@ 10.0	@ 20.0
10	290	.6%	.06%	.03%
	100	1.76%	.18%	.09%
	50	3.52%	.35%	.18%
20	290	2.44%	.24%	.12%
	100	7.08%	.71%	.35%
	50	14.17%	1.42%	.71%
30	290	5.48%	.55%	.27%
	100	15.88%	1.59%	.79%
	50	31.76%	3.18%	1.59%