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EVALUATION OF PRESSURE TRANSDUCERS TO MEASURE
SURFACE LEVEL IN THE WASTE STORAGE TANKS

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SUMMARY

This report describes the results of tests conducted at the Pacific Northwest Laboratory (PNL) to determine if pressure transducers can be used to measure the surface level in the waste tanks. A survey was first conducted to evaluate which, if any, commercially available pressure transducers were available that could meet the requirements for use in the waste tanks. More than 35 companies were contacted to determine if they manufactured a pressure transducer that could be used in the 101-SY waste tank. The three basic requirements for a pressure transducer for this application were that they were radiation-hardened, could withstand a caustic environment, and were certified to be intrinsically safe. No manufacturer was able to meet all three of these requirements with a commercially available product. Seven companies were able to meet the requirements for being radiation-hardened and being able to withstand the caustic environment. However, only two of the nine companies were willing to supply a pressure transducer for laboratory testing. The two pressure transducers that were tested in this program were the VEGA D36-38 from HiTech Technologies, Inc., and the KP-1911-A from Kaman Instrumentation Corporation.

Pressure transducers operate on the principle that the pressure at the location of a sensor increases directly with the depth of the liquid above it. A liquid is required in order for these devices to operate. For these tests, water was first used to determine the ideal operation of the devices, then the devices were placed in a 101-SY waste tank simulant. The simulant had a specific gravity of 1.96 and had the consistency similar to the convective layer in the 101-SY waste tank. In order to determine the surface level with pressure transducers, the density of the material needs to be known. By using two or more of these devices at a known vertical separation from each other, the pressure difference between the two devices can be used to determine the density of the liquid. In addition to testing the accuracy and repeatability of each of the pressure transducers, tests were also conducted to determine the output of the pressure transducer as the temperature of the media is changed. The output of pressure transducers is dependent on temperature as well as pressure. In addition, the pressure transducers were left in the

simulated waste tank material for approximately two months to determine the amount of drift in their output over time and to determine if they show any signs of deterioration in the caustic environment. They were also subjected to radiation exposure in the gamma pit.

The results of the tests indicate that the Kaman transducer is capable of operating in the waste tank environment. It withstood being placed in the simulated waste tank material for 55 days and withstood a radiation exposure in the gamma pit equivalent to five years at 1000 R/hr without any noticeable degradation of its performance. However, it exhibited an accuracy of measuring liquid level of only about ± 0.34 inch in simulated 101-SY waste material and needs to be compensated for temperature variations (which resulted in another ± 0.06 inches error in measuring the accuracy in simulated waste material). The accuracy of a transducer is a function of its range, and the range of the pressure transducer tested in this study was 0-20 psia. If the range is decreased to 0-5 psia, it may be possible to achieve 0.25 inch accuracy with this device in the waste tank. The commercially available Kaman pressure transducer system can operate with a cable with a maximum length of 45 feet. Discussions need to be held with the manufacturer to determine what may be done if longer cable lengths will be needed for the waste tank applications.

The VEGA transducer exhibited an instability that would not make it useful for waste tank applications. The instability is apparently due to the impedance of the radiation-resistant cable. The transducer became very sensitive to temperature fluctuations of the oscillator, which resulted in instantaneous changes in the current output of the transducer that were equivalent to a several-inch change in level.

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BACKGROUND

The surface level of the contents of the waste tanks has been measured for several years using a Food Industry Corporation (FIC) electrical contact probe, manual-weighted tape, and zip cords. All of these devices exhibit problems in determining the distance to the waste surface. When the FIC probe contacts a liquid surface, electrical contact is registered and the liquid level is determined by measuring the amount of cable that was extended into the tank when electrical contact occurred. The desired accuracy for measuring the surface level is ± 6.4 mm (± 0.25 inch). The surface level is automatically recorded using a data acquisition system at predetermined times, depending on the status of the tank. With the manual tape, a weight is placed at the end of a steel tape. The tape is lowered until a current meter connected between the tape and the riser shows a full-scale deflection. The level reading is taken from the tape. With the zip cord, the pre-stretched cord is lowered through a riser until the operator detects slack in the cord. The amount of cord that is released until slack is noted in the cable is used to determine the surface level.

One of the problems with measuring surface level using the contacting FIC probe, as well as with the manual tape, is that crystals form on the probe or weight as it is withdrawn from the liquid material. This leads to inaccuracies in subsequent measurements made with the device. Another problem with the FIC probe and manual tape is that it cannot determine the level of solid materials if the surface dries out and becomes non-conductive. Also, the weight of the probe or weight at the end of the FIC probe or manual tape may eventually pound a hole into the solid material, resulting in a false reading. Finally, because the dried-out sludge level can be so uneven and the salt cakes may shift, the probe may produce false readings of the actual (average) level of material in the tanks. The manual tape can also give inaccurate readings due to thermal expansion of the steel tape. The level measurement with the zip cord is dependent on the subjective determination of slack by the operator.

A radar gauge was installed in the 101-SY waste tank as a non-contacting method to measure surface level. However, its accuracy was affected by the changing surface conditions (Peters et al. 1992; Peters et al. June 1993).

Thus, a better method needs to be found to determine the level of the surface. Pressure transducers have been used for a long time to measure level and density of a liquid in a storage tank. The pressure at any given level in the liquid is related to the height and density of the liquid by the equation:

$$P = g \int_0^h \rho(z) dz$$

where P = pressure at a given level in the liquid
ρ = density of the liquid
g = gravitational constant
h = height of liquid above pressure transducer

In a homogeneous liquid, the density of the liquid and the gravitational constant would not change; thus, any change in the pressure would directly indicate a change in the height of the liquid above the pressure transducer. The density of the liquid could be determined by placing two pressure transducers a known distance apart and determining the difference in pressure between the two transducers.

A few years ago, pressure transducers were used in waste tank 101-SY to determine level and density; however, they failed prematurely because the manufacturer used a potting material that did not withstand the caustic waste tank environment. The purpose of this project was to evaluate whether commercial pressure transducers are available that could be used to measure the surface level in the waste storage tanks at Hanford. A pressure transducer could not be used in a tank that contains a hard surface. Even the tanks which contain material that is liquid in nature generally do not contain a viscous liquid like water, but contain sediments, like sludge, that could clog a bubbler system (Peters et al. October 1993). However, pressure transducers are relatively inexpensive devices that are widely used in industry, including in harsh and radioactive environments; hence, commercially available systems may be able to be used for level and density measurements in the waste tanks at Hanford.

CONCLUSIONS

The Kaman transducer was able to withstand the waste tank environment. No degradation in its performance was noted when placed in simulated waste tank material for 55 days. In addition, it was able to withstand a cumulative gamma radiation exposure of 4.4×10^7 R, which is equivalent to an exposure of five years at 1000 R/hr, without any degradation of its performance. The soft cable, whose radiation resistance was not previously determined, withstood a gamma radiation exposure of 1.76×10^7 R, which is equivalent to an exposure of two years at 1000 R/hr, without any noticeable degradation. In order to accurately measure the level, the output of the Kaman transducer needs to be corrected for barometric pressure and temperature. Even with these corrections, the Kaman transducer tested in this study exhibited a ± 0.40 inch accuracy in measuring the surface level in 101-SY simulant. This is $\pm 0.14\%$ of its full-scale output. The error in measuring level could be decreased by decreasing the range of the transducer. The transducer tested had a range of 0-20 psia. The voltage output of the Kaman transducer would have to be converted to current in order to be compatible with the 4-20 ma input required for the data logging system at the Hanford Tank Farms. The manufacturer does not recommend that the Kaman transducer operate with a cable over 45 feet long. This may be a problem for the waste tank applications. Discussions need to be held with the manufacturer to determine what may be done to their transducer to increase the cable length. Also, these pressure transducers need to be evaluated for intrinsic safety.

The VEGA transducer did not exhibit the accuracy or stability to be used in waste tank applications. At best, the system exhibited an accuracy of ± 0.56 inch in measuring the surface level in water. It exhibited an instability that resulted in output current that would indicate a several-inch change in the level instantaneously. On the VEGA transducer, the change in capacitance as the diaphragm deflects is very low, on the order of a few picofarads. Connections inside the oscillator housing need to be made carefully, with the wires properly shielded and connected; otherwise, the system will not operate properly. In addition, the manufacturer determined that with the radiation-resistant cable, changing the temperature of the

oscillator housing will greatly affect its output. The oscillator needs to be placed in a temperature-controlled environment. This kind of sensitivity is not consistent with the rugged environment the system would be exposed to in the tank farms.

Finally, the operations manual for the VEGA transducer is poorly written. The parameters that were used to set up the system were determined by trial and error. Based on the information from the manual, it appears that the VEGA system is usually operated in the mode where the numbers displayed on the transmitter are the percentage of the tank filled, instead of current output used in this test and needed for the data logging system on the tank farms. This output is not accurate enough for waste tank applications.

RECOMMENDATIONS

Of the two transducers tested during this study, only the Kaman transducer is capable of operating in the waste tank environment. Its accuracy may not be as high as is available with other methods for measuring the surface level (Peters et al. September 1993); however, by using more than one transducer, a pressure transducer system would be able to determine density of the contents in the waste tanks. Also, by using pressure transducers to measure surface level, the determination of the surface level would not be affected by the movement of "waste bergs" in the waste tank. Discussions should be held with Kaman Instrumentation Corporation regarding development of a pressure transducer that could operate with longer cables. The manufacturer needs to be contacted regarding evaluation of this pressure transducer for intrinsic safety.

Many manufacturers of pressure transducers were contacted in this study. Based on the results of this study, it appears that the only alternative to using the Kaman pressure transducer is to work with a manufacturer to develop a pressure transducer specifically for the waste tank application. Commercial pressure transducers are not designed to meet the harsh environment that occurs for the waste tank applications.

SURVEY RESULTS

A survey of commercial pressure transducers was conducted to determine if devices are available that could be used for waste tank applications. The results are summarized in Appendix A.

The three basic requirements a pressure transducer must exhibit in order to be used in waste tank 101-SY are that it withstand the radiation (1000 R/hr), withstand the caustic liquid (Ph 14), and be certified to be intrinsically safe. There were no commercially available pressure transducers that could meet those three basic requirements. Add to these requirements the temperature variations that are experienced in the waste tank and the need for sensor accuracy (even when salt crystals may form on the transducer diaphragm), then one can see that the waste tank requirements are severe. This was expressed in a letter from a supplier of custom pressure transducers:

"Your environment is one of the worst that there is, with hard radiation, small driving potential, unstable temperature and phase relationships, corrosive environment, restricted envelope, and explosive atmosphere--all as difficulties to contend with. While most of these are common to our routine considerations for the downhole oil or gas well environment, the combination of small driving potential, coupled with the tendency of the material to crystallize, are new considerations for us."^a

From the survey, it became apparent that seven companies manufacture commercially available pressure transducers that could meet the requirements for radiation-resistance and withstanding a caustic environment. The seven companies were:

1. C. J. Enterprises	5. Paine Corporation
2. Eaton Corporation	6. Sensotron
3. HiTech Technologies, Inc.	7. Statham Instruments.
4. Kaman Instrumentation Corporation	

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^a Letter sent to Timothy Peters from Bud Dublin of Industrial Sensors & Instruments, Inc., August 13, 1993.

A letter was sent to each company requesting a price quotation for a single pressure transducer for testing purposes in three different pressure ranges: 0-5 psig, 0-15 psig, and 0-25 psig. The requirements for the pressure transducer were given as follows:

1. The pressure transducer and cabling needs to be radiation-hardened to withstand up to 1000 R/hr.
2. The pressure transducer and cabling will be submersed in a caustic liquid, pH 14.
3. The pressure transducers and cabling must withstand and accurately measure pressures within a temperature range of 50°F-150°F.
4. In-line signal amplifiers may not be able to be located any closer than 60 feet from the transducers. The instrumentation building may be 300-600 feet from the transducers.
5. The pressure transducers need to be intrinsically safe to operate in a hydrogen atmosphere. It would be desirable if the pressure transducers were certified intrinsically safe, but if this is not possible, then the company that supplies the pressure transducers must be willing to provide design information to our engineers so their safety can be evaluated.
6. The maximum size allowed for the pressure transducer in their present location is 1.75 inches in diameter and 5.25 inches long. However, other sizes will be considered up to 3.5 inches in diameter.
7. The pressure transducer placed near the top of the tank will need a range of 0-5 psig and the range will increase to 0-25 psig near the bottom of the tank. The tanks are 50 feet deep.
8. The tank where the pressure transducer is immediately needed undergoes changes in temperature (20° F/5 minutes) and pressure (1 psi/5 minutes). The pressure transducer must accurately read the pressure during these conditions.

Only Kaman Instrumentation Corporation; Sensotron; C. J. Enterprises; and HiTech Technologies, Inc., were willing to quote a price for a pressure transducer. Industrial Sensors & Instruments, Inc., was willing to perform a feasibility study on designing a custom system. The pressure transducer supplied by C. J. Enterprises uses a U-tube arrangement which would be expected to clog up in the waste tank materials (Peters et al. 1993); hence, it was not ordered. Purchase orders were placed for pressure transducers from the remaining three companies. However, Sensotron was not able to supply a

pressure transducer they felt could meet the environment in a reasonable period of time; therefore, the order for this transducer was cancelled. Pressure transducers from the remaining two companies were tested in this study.

TEST RESULTS

TEST SET-UP

Figure 1 shows the apparatus which was designed to test the pressure transducers. Because of the caustic nature of the simulant and the amount of simulant available, the test vessel volume was minimized as much as possible. The vessel was made out of a 5-foot section of 4-inch clear polyvinyl chloride (PVC) pipe which held approximately 3 gallons of liquid. Visual liquid level was determined with standard tape measure, fastened lengthwise along the side of the test vessel. A 1-inch valve was provided at the bottom of the vessel to drain the test vessel during tests. All components and materials which came into contact with the simulant (or the simulant vapors) were made of

FIGURE 1. Test Apparatus

stainless steel, polyethylene, or PVC. The constituents of the waste simulant used in this test are shown in Table 1. The specific gravity of the simulant was measured to be 1.96.

The pressure transducers were tested first in water, to determine their accuracy, precision, and repeatability, and then in simulated waste material to determine the operation of the measurement systems in a media containing various particulates. This was done at approximately 70°F, 100°F, and 130°F to determine the effect of the output of the pressure transducers on temperature. Both pressure transducers had a range of 0-20 psia.

DISCUSSION OF TESTS

Kaman Pressure Transducer

The Kaman pressure transducer operates by measuring the change of impedance between a plate mounted on the diaphragm of the pressure transducer and an eddy current coil located in the pressure transducer. This impedance is a function of the distance between the eddy current coil and the conductive plate, which occurs as the diaphragm moves due to the change in the external

TABLE 1. Chemical Components of Simulant

Component	Weight Percentage (%)
H ₂ O	31.83
NaNO ₂	17.95
Na _{1.21} AlO ₂	15.53
NaNO ₃	12.31
NaOH	6.45
Na ₃ PO ₄	4.48
Na ₃ HEDTA	3.38
Na ₂ CO ₃	2.79
NaCl	2.02
Na ₄ EDTA	1.65

pressure. The Kaman pressure transducer is designed to be used in high temperature and high humidity environments, such as in boilers. It comes attached with a metal sheath cable, up to a maximum of 20 feet. A soft line cable, up to a maximum of 30 feet, can be attached to the end of the metal sheath cable. The manufacturer does not recommend that the total cable length exceeds 45 feet. In the system that was tested, the metal sheath cable was 5 feet and the soft line cable was 13 feet long. The manufacturer claims the standard soft line cable will deteriorate over time in a radiation field and recommends that it be placed outside the radiation zone. However, testing conducted in this program indicates the soft line cable is able to withstand a significant amount of radiation exposure.

The output of the transducer is monitored by connecting a voltmeter to the output from the signal conditioning electronics package supplied with the transducer. In order to obtain sufficient significant digits on the voltmeter used to measure the output of this transducer, the voltage output of the transducer was amplified ten times. In the results discussed in this report for the Kaman transducer, this amplification factor was eliminated, and the voltages reported herein correspond to the output of the transducer without this amplification factor.

Water

The first tests of the Kaman transducer were conducted in water. The results are shown in Tables B1 through B4 in Appendix B. The test results indicate that the output of the Kaman transducer changed 1.8 mv for every 1-inch change in the level. This change in the output voltage with a change in the level ($\Delta V/\Delta h$) was independent of temperature, when the temperature ranged from 70°F to 125°F. However, as will be discussed later in this section, the amount of output voltage (V) from the pressure transducer is dependent on the temperature (T) of the pressure transducer. The change in output voltage with a change in the level was repeatable to ± 0.2 mv, which is equivalent to a level change of ± 0.11 inch. For two runs done on the same day, the repeatability of the transducer was ± 0.3 mv or ± 0.18 inch. However, the output of the device for a given level of liquid being measured varied significantly from one day to the next, which is shown in Table B5. This is apparently due to the change in atmospheric pressure. The first test with the

transducer in water, which is shown in Table B5, indicates a change of 6.2 mv overnight with the same level of water in the tube. As discussed previously, the transducer had a sensitivity of 1.8 mv/in.; hence, this is equivalent to a change of 3.4 inches of water or 0.25 inch of mercury (specific gravity 13.6). The actual barometric pressure measured at the Hanford weather station during this time period changed 0.23 inch of mercury. Thus, in order to properly analyze the test data, it was necessary to correct the data shown in Tables B1 through B4 using the data from Table B5. A test run to measure different levels in the test tank took only about 13 minutes; thus, it was generally not necessary to correct for barometric pressure variations to determine sensitivity and repeatability of the pressure transducer for a given test. However, it was necessary to correct for changes in atmospheric pressure when the test was conducted for a long period of time and/or on different days.

The amount of output voltage from the Kaman transducer is also dependent on temperature, as shown in Figure 2. The voltage output of the device changed 0.1 mv/°F, which is equivalent to 0.06 inch/°F. Notice that the data points in Figure 2 are more scattered for the water than for the simulant. This is possibly due to the fact that the water did not retain the heat as well as the simulant.

Simulant

The tests with the Kaman pressure transducer in the simulated waste tank material are shown in Tables B6 through B8 in Appendix B. The results indicated that the output of the pressure transducer changed 2.9 mv for every 1-inch change in the level of the material. This change is 61% greater than what was observed in water, even though the density of the simulant is 100% greater than it is for water. Again, the magnitude of this change with level was independent of temperature when the temperature ranged from 70°F to 135°F. The average error in measuring this change was ± 0.4 mv or ± 0.14 inch. Again, the output of the transducer for a given level of simulant in the tube varied with barometric pressure, as shown in Table B5. The average error when the data was taken on the same day was ± 0.3 mv or ± 0.10 inch, but was as high as

FIGURE 2. Change in Output Voltage of Kaman Transducer as a Function of Temperature

± 3.9 mv or ± 1.34 inches when the data was taken on different days. Again, the error in measuring the liquid level that occurred on different days was due to changes in the barometric pressure. The change in barometric pressure for

this case was measured to be 0.35 inch of mercury, and this level change is equivalent to 0.37 inch of mercury.

As was seen in the water and shown in Figure 2, the output of the pressure transducer changed 0.09 mv/°F, which is equivalent to a level change of 0.03 inch/°F. The data shown in Figure 2 for the pressure transducer in water or simulant indicates that the change in the output of the pressure transducer as a function of temperature is approximately equal. If the data from both the water and the simulant is plotted together, one obtains the following equation that describes the relationship between the change in the voltage output of the pressure transducer and with temperature (relative to the voltage output of the pressure transducer at 72°F):

$$\Delta V = - 6.56 + 0.0944 T$$

where ΔV = voltage change in mv
T = temperature in °F

The correlation factor for this linear relationship is $r=0.987$. In comparing the experimental data with the output current calculated from this equation, it is determined that the average error in measuring the level due to temperature changes is equivalent to ± 0.06 inch change in the level measurement.

The Kaman transducer was placed in the highly caustic simulated waste tank material, which was held at room temperature (approximately 72°F) for 55 days. The level of the simulated waste tank material did not change during this period. The transducer continued to operate during this period with no noticeable degradation in its output or the transducer face. During this period, the voltage output of the transducer was monitored twice a day and the barometric pressure was also recorded. The results of this test indicate that the current output of the transducer in the simulated waste tank material exhibited approximately a 24 mv change for every 1-inch change in barometric pressure (standard deviation of ± 1 mv). Thus, it can be seen that, with the transducer indicating a 2.9 mv change for every 1-inch change in level, the system needs to be corrected for barometric pressure. If it is desired to measure the level to 0.1 inch, then the pressure of the atmosphere inside the

tank has to be monitored to 0.01 inch. However, the standard deviation of the readings during this long-term test when the transducer was placed in the simulant was ± 1 mv, which implies that the pressure transducer cannot read level any better than ± 0.34 inch, or $\pm 0.12\%$ of the transducer's full-scale output. The pressure range of the transducer that was tested was 0-20 psia. Decreasing the range to 0-5 psia would imply that the accuracy could be increased by a factor of four, ± 0.25 mv or ± 0.09 inch. Add this to the error due to temperature (± 0.06 inch), and even under best conditions, a 0.25-inch accuracy is only barely attainable.

Radiation Exposure

The Kaman pressure transducer was placed in the gamma radiation pit to determine its ability to withstand the radiation in the waste tanks. The transducer was placed in the radiation pit for two weeks with a dose of 2.6×10^4 R/hr. This is equivalent to an exposure of one-half year at a rate of 1000 R/hr that is expected in the waste tanks. The dose rate was then increased to 5.2×10^4 R/hr for four weeks. The Kaman transducer was thus exposed to a total 4.40×10^7 R, which is equivalent to five years exposure of gamma radiation at 1000 R/hr. The transducer and the metal sheath cable attached to it did not exhibit any degradation of its performance after being exposed to gamma radiation. This is shown in the data in Table B9 in Appendix B.

In addition, a printed circuit board, radiation-resistant epoxy, and regular commercial epoxy were exposed to the radiation in the gamma pit. The material was first exposed at a dose rate of 2.6×10^4 R/hr for one week, for a cumulative dose of 4.4×10^6 R. No noticeable degradation was noticed on the items except that the printed circuit board and the commercial epoxy were discolored. The dose rate was increased to 5.2×10^4 R/hr for four weeks. Other than discoloration of the printed circuit board and the commercial epoxy, there was no noticeable degradation in the strength of these items after being exposed to a cumulative dose of 3.96×10^7 R, which is equivalent to a gamma exposure of 4.5 years at 1000 R/hr. The radiation-resistant epoxy did not even exhibit discoloration after this exposure.

The soft cable for the transducer was placed in the gamma radiation pit for two weeks at a dose rate of 5.24×10^4 R/hr. There was no degradation in the appearance or the performance of the soft cable after an equivalent exposure of 1.76×10^7 R, which is equivalent to a two-year exposure of gamma radiation at 1000 R/hr.

VEGA Pressure Transducer

In the VEGA pressure transducer, a deflection in the diaphragm of the pressure transducer due to a change in the external pressure is transmitted to a plunger-type capacitor located inside the pressure transducer. The capacitance of this capacitor thus changes proportionally with the pressure. This capacitance is then converted to a 4-20 ma output signal. The VEGA transducer did not produce a 4-20 ma output current that could be displayed on its transmitter. In order to obtain the current output from the pressure transducer, it was necessary to connect an ammeter to terminals 16 and 18 of the transmitter. The display on the transmitter indicates percentage of the tank filled or the level of the tank in meters, which did not have enough significant digits to accurately gauge changes in the level that are required for the waste tank applications.

The VEGA system was tested with a intrinsically safe barrier in the system (IS barrier model 145), which was supplied by the manufacturer.

The transmitter contains various programming functions. The parameters used for testing the VEGA transducers are shown in Table 2. The VEGA operations manual is not well written. By trial and error, it was determined that the empty adjustment (#11) should be set so the current output from the transducer is approximately 5 ma when it is in air and the full adjustment (#12) should be set 0.3 units greater than the empty adjustment. This obtains the largest change in the current output with a given change in level. However, this limits the range of measurement of the instrument to 20 feet for a liquid which has a density similar to water.

TABLE 2. Set-Up Parameters for VEGA Transmitter

<u>Mode Number</u>	<u>Mode Description</u>	<u>Parameter Value</u>
01	Measuring range in bar	0.00
02	Minimum sensor current in ma	4.00
03	Maximum sensor current in ma	20.00
10	Selection of adjustment procedure (ma)	5
11	Empty adjustment	6.92
12	Full adjustment	7.22
15	Measuring unit (meters)	CH1H m
16	Decimal point	0.000
17	Integration time (sec.)	1

Water

The system was first tested in water at approximately 72°F. The tube was filled with water to approximately 50 inches above the transducer. The results, shown in Table B10, indicate that the transducer system was very unstable. The output current would vary without any change in the level or other operating parameters in the system. As noted, the output current is different between run 1 and run 2 because the output of the transducer varied and the operating parameters had to be readjusted. Although the absolute value of the current output from the transducer varied from the two runs, the change in the current for a 2-inch increment was consistent and could be compared for the two runs. This analysis indicates that this transducer system exhibited a 0.057 ma change in current for every 1-inch change in level. However, the error in measuring this increment was ± 0.032 ma, which is equivalent to an error of ± 0.56 inch. In addition, during the test, the system exhibited an instability of up to 0.107 ma instantaneously, which is equivalent to an error in measuring the level of 1.88 inches, and up to 0.695 ma over a period of an hour, which is equivalent to an error of 12.19 inches. A data logger was placed on the system to log its output current overnight. The output current varied +1.390 ma to -2.535 ma from the mean. This is equivalent to an error in level measurement of +24.4 inches and -44.5 inches. The barometric pressure did not change overnight. Efforts were made to determine the source of this instability. The system was even sent back to the manufacturer. It appears that the oscillator with the radiation cable

attached to it is very sensitive to temperature changes. Holding a hand over the plastic case of the oscillator caused the output current from the transducer to increase to its maximum 20 ma. Blowing air across the case would cause the output of the transducer to go down to its minimum 4 ma value. Attempts were made to shield the cable and vary the method of attaching the wires in the oscillator housing, with no increase in the stability of the system.

In further discussions with the manufacturer, it was determined that the oscillator was not compatible with the radiation-hardened cable. A new oscillator was supplied, and the transducer system was not as sensitive to external stimulus, such as placing a hand over the plastic case of the oscillator. However, the system continued to exhibit an instability which was equivalent to ± 6.36 inches change in level. Increasing the integration time that the transducer system uses to average the feedback from the sensor from one second to ten seconds changed this error to ± 3.62 inches, and changing the integration time to 100 seconds changed the error in measuring level to ± 1.09 inches. Therefore, it was determined that the VEGA transducer exhibited too large an instability to be used for the waste tank application, and testing was suspended on this device.

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APPENDIX A

LIST OF COMMERCIALLY AVAILABLE PRESSURE TRANSDUCERS

NOTE: These are vendors contacted as part of this study. All possible vendors may not be on these lists. Items are listed alphabetically by manufacturer names. Comments are based on discussion held with the manufacturers and personnel at Hanford who have used these devices. They represent only the opinion of the individual and are included only for completeness of this survey. These opinions are not to be taken as an endorsement of a product.

APPENDIX A

PRESSURE TRANSDUCERS

NAME   A. L. Design Inc
CONTACT   Andrew Lenkei
ADDRESS   1411 Military Road
CITY   Buffalo, NY 14217
TELEPHONE   716-875-6240

MODEL	LM	RADIATION-RESISTANT	No
DIAMETER	1.12 in.	WITHSTAND CAUSTIC	
LENGTH	2 in.	ENVIRONMENT	Maybe
ACCURACY	±0.4% FSO	MATERIAL	S.S.
TEMPERATURE	160°F	INTRINSICALLY SAFE	No
TEMP. EFFECT	1.0%/100°F	FIT IN PRESENT TREE	Yes
PRICE			

NOTES: Pressure Transducers are secondary products.

NAME   Amtec
CONTACT
ADDRESS   920 Pennsylvania Blvd.
CITY   Feasterville, PA 19053
TELEPHONE   813-536-7831

MODEL	851	RADIATION-RESISTANT	No
DIAMETER	1.25 in.	WITHSTAND CAUSTIC	
LENGTH	6.5 in.	ENVIRONMENT	Yes
ACCURACY	±0.25% FSO	MATERIAL	316 s.s.
TEMPERATURE	180°F	INTRINSICALLY SAFE	Yes
TEMP. EFFECT	3.2 %/100°F	FIT IN PRESENT TREE	No
PRICE			

NOTES

PRESSURE TRANSDUCERS

NAME Ashcroft
CONTACT
ADDRESS 250 East Main Street
CITY Strafford, CT 06497
TELEPHONE 203-378-8281

MODEL	Many	RADIATION-RESISTANT	No information
DIAMETER	in.	WITHSTAND CAUSTIC	
LENGTH	in.	ENVIRONMENT	No information
ACCURACY	± % FSO	MATERIAL	No information
TEMPERATURE	°F	INTRINSICALLY SAFE	No information
TEMP. EFFECT	%/100°F	FIT IN PRESENT TREE	No information
PRICE			

NOTES: Low Range Delta-P Transducers.

NAME Barksdale
CONTACT Frita
ADDRESS 3211 Fruitland Ave.
CITY Los Angeles, CA 90058
TELEPHONE 213-589-6181

MODEL	3769	RADIATION-RESISTANT	No
DIAMETER	1.75 in.	WITHSTAND CAUSTIC	
LENGTH	10 in.	ENVIRONMENT	Yes
ACCURACY	±0.1% FSO	MATERIAL	316 s.s.
TEMPERATURE	167°F	INTRINSICALLY SAFE	No
TEMP. EFFECT	0.83%/100°F	FIT IN PRESENT TREE	No
PRICE	\$725		

NOTES

PRESSURE TRANSDUCERS

NAME C. J. Enterprises
CONTACT M. Cantor
ADDRESS P.O. Box 570430
CITY Tarzana, CA 91356
TELEPHONE 818-996-4131

MODEL CJVR-3056
DIAMETER 1.5 in.
LENGTH 3.5 in.
ACCURACY $\pm 0.5\%$ FSO
TEMPERATURE 170°F
TEMP. EFFECT 3%/100°F
PRICE \$4,500+

RADIATION-RESISTANT Yes
WITHSTAND CAUSTIC
ENVIRONMENT Maybe
MATERIAL 347 s.s.
INTRINSICALLY SAFE No
FIT IN PRESENT TREE Yes

NOTES

NAME Data Instruments, Inc.
CONTACT Jim King
ADDRESS 100 Discovery Way
CITY Acton, MA 01720
TELEPHONE 508-264-9550

MODEL BL
DIAMETER 0.81 in.
LENGTH 3.1 in.
ACCURACY $\pm 1\%$ FSO
TEMPERATURE 180°F
TEMP. EFFECT 2%/100°F
PRICE

RADIATION-RESISTANT No
WITHSTAND CAUSTIC
ENVIRONMENT Yes
MATERIAL 316 s.s.
INTRINSICALLY SAFE Yes
FIT IN PRESENT TREE Yes

NOTES

PRESSURE TRANSDUCERS

NAME DCT Instruments
 CONTACT Mark Hoffman
 ADDRESS 1165 Chambers Road
 CITY Columbus, OH 43212
 TELEPHONE 614-481-7777

MODEL PT
 DIAMETER 1.5 in.
 LENGTH 4-5 in.
 ACCURACY $\pm 0.1\%$ FSO
 TEMPERATURE 170°F
 TEMP. EFFECT 2%/100°F
 PRICE

RADIATION-RESISTANT No
 WITHSTAND CAUSTIC
 ENVIRONMENT Maybe
 MATERIAL 304 s.s.
 INTRINSICALLY SAFE No
 FIT IN PRESENT TREE Yes

NOTES

NAME Design Analysis
 CONTACT Robin
 ADDRESS 75 West 100 South
 CITY Logan, UT 84321
 TELEPHONE 801-753-2212

MODEL H-300
 DIAMETER 1.25 in.
 LENGTH 7 in.
 ACCURACY $\pm 0.02\%$ FSO
 TEMPERATURE 120°F
 TEMP. EFFECT 0.02%/100°F
 PRICE

RADIATION-RESISTANT No
 WITHSTAND CAUSTIC
 ENVIRONMENT Maybe
 MATERIAL S.S., RTV
 INTRINSICALLY SAFE No
 FIT IN PRESENT TREE No

NOTES

PRESSURE TRANSDUCERS

NAME Druck, Inc.
CONTACT
ADDRESS 4 Dunham Drive
CITY New Fairfield, CT 06812
TELEPHONE 203-746-2494

MODEL	PDCR 143	RADIATION-RESISTANT	No
DIAMETER	1 in.	WITHSTAND CAUSTIC	
LENGTH	4 in.	ENVIRONMENT	Yes
ACCURACY	±0.1% FSO	MATERIAL	Hastelloy
TEMPERATURE	160°F	INTRINSICALLY SAFE	Yes
TEMP. EFFECT	2%/100°F	FIT IN PRESENT TREE	Yes
PRICE	\$800		

NOTES: The manufacturer is in England; this is a U.S. distributor.

NAME Druck, Inc.
CONTACT
ADDRESS 4 Dunham Drive
CITY New Fairfield, CT 06812
TELEPHONE 203-746-2494

MODEL	PTX 600	RADIATION-RESISTANT	No
DIAMETER	1.5 in.	WITHSTAND CAUSTIC	
LENGTH	3.5 in.	ENVIRONMENT	Yes
ACCURACY	±0.08% FSO	MATERIAL	Hastelloy
TEMPERATURE	175°F	INTRINSICALLY SAFE	Yes
TEMP. EFFECT	1%/100°F	FIT IN PRESENT TREE	Yes
PRICE	\$800		

NOTES: The manufacturer is in England; this is a U.S. distributor.

PRESSURE TRANSDUCERS

NAME Eagle-Picher Industries, Inc.
 CONTACT Ed Bowie
 ADDRESS 2560 General Armistead
 CITY Valley Forge, PA 19485
 TELEPHONE 215-539-4400

MODEL	110S	RADIATION-RESISTANT	No
DIAMETER	3.19 in.	WITHSTAND CAUSTIC	
LENGTH	4.94 in.	ENVIRONMENT	No
ACCURACY	±0.25% FSO	MATERIAL	A1 & 303 s.s.
TEMPERATURE	176°F	INTRINSICALLY SAFE	Yes
TEMP. EFFECT	0.02%/100°F	FIT IN PRESENT TREE	No
PRICE			

NOTES: Not interested in pursuing our application.

NAME Eaton Corporation
 CONTACT R. Barnes
 ADDRESS 15 Durant Avenue
 CITY Bethel, CT 06801
 TELEPHONE 203-796-6000

MODEL	41SG404	RADIATION-RESISTANT	Yes
DIAMETER	1.37 in.	WITHSTAND CAUSTIC	
LENGTH	3.5 in.	ENVIRONMENT	Maybe
ACCURACY	±0.28% FSO	MATERIAL	15-5 pH s.s.
TEMPERATURE	250°F	INTRINSICALLY SAFE	Yes
TEMP. EFFECT	0.75%/100°F	FIT IN PRESENT TREE	Yes
PRICE	\$1-\$2K		

NOTES: They have product ready to certify as intrinsically safe.

PRESSURE TRANSDUCERS

NAME   Endevco
 CONTACT
 ADDRESS   30700 Rancho Viejo Road
 CITY   Mission Viejo, CA 92675
 TELEPHONE   714-493-8181

MODEL	Many	RADIATION-RESISTANT	No
DIAMETER	0.9+ in.	WITHSTAND CAUSTIC	
LENGTH	0.4+ in.	ENVIRONMENT	Maybe
ACCURACY	±0.5% FSO	MATERIAL	S.S. & si.
TEMPERATURE	250°F	INTRINSICALLY SAFE	No
TEMP. EFFECT	0.02%/100°F	FIT IN PRESENT TREE	Yes
PRICE			

NOTES: Past experience indicates that these transducers are highly reliable. Frequent aerospace applications.

NAME   Entran Devices, Inc.
 CONTACT   Michael MacDermott
 ADDRESS   10 Washington Ave.
 CITY   Fairfield, NJ 07004
 TELEPHONE   800-635-0650

MODEL	EPN	RADIATION-RESISTANT	No
DIAMETER	0.4 in.	WITHSTAND CAUSTIC	
LENGTH	0.15 in.	ENVIRONMENT	Maybe
ACCURACY	±0.25% FSO	MATERIAL	304 s.s.
TEMPERATURE	170°F	INTRINSICALLY SAFE	
TEMP. EFFECT	2%/100°F	FIT IN PRESENT TREE	Yes
PRICE	\$380 + \$7/ft.		

NOTES: Electronics outside housing. In the past, the transducers from this organization have exhibited poor reliability and low sensitivity. Not recommended for this application.

PRESSURE TRANSDUCERS

NAME   HiTech Technologies, Inc.
 CONTACT   Leif C. Lindvall
 ADDRESS   P.O. Box 535
 CITY   Newtown, PA 18940
 TELEPHONE   800-367-5383

MODEL	VEGA D38N EX	RADIATION-RESISTANT	Yes
DIAMETER	3.84 in.	WITHSTAND CAUSTIC	
LENGTH	4.64 in.	ENVIRONMENT	Yes
ACCURACY	±0.2% FSO	MATERIAL	316 s.s.
TEMPERATURE	392°F	INTRINSICALLY SAFE	Yes
TEMP. EFFECT	NI%/100°F	FIT IN PRESENT TREE	No
PRICE	\$5,800		

NOTES: Made in Germany. This is a U. S. distributor. Previous experience indicates problems with factory support.

NAME   Hewlett Packard
 CONTACT   Chuck Little
 ADDRESS   P.O. Box 58059
 CITY   Santa Clara, CA 95052
 TELEPHONE   503-598-8103

MODEL	2813	RADIATION-RESISTANT	No
DIAMETER	1.5 in.	WITHSTAND CAUSTIC	
LENGTH	34.3 in.	ENVIRONMENT	No
ACCURACY	±0.01% FSO	MATERIAL	Nitronic 50
TEMPERATURE	350°F	INTRINSICALLY SAFE	No
TEMP. EFFECT	0.02%/100°F	FIT IN PRESENT TREE	No
PRICE	\$28,000		

NOTES: Pressure range 200-11,000 psi. No longer made. ±1 psi accuracy and repeatability.

PRESSURE TRANSDUCERS

NAME Honeywell Inc, Industrial Automation and Control
 CONTACT Richard C. Delmonte
 ADDRESS 600 108th Ave. NE, 6th Floor
 CITY Bellevue, WA 98004
 TELEPHONE 206-453-7556

MODEL	STR 126	RADIATION-RESISTANT	No information
DIAMETER	3 in.	WITHSTAND CAUSTIC	
LENGTH	N.I. in.	ENVIRONMENT	Yes
ACCURACY	±0.2% FSO	MATERIAL	316 s.s.
TEMPERATURE	185°F	INTRINSICALLY SAFE	Yes
TEMP. EFFECT	0.7%/100°F	FIT IN PRESENT TREE	No
PRICE			

NOTES: Is available in Monel and Hastelloy C also. Lowest pressure range 10 inches of water. Remote diaphragm seal. Information supplied by Kaiser personnel.

NAME IMO Industries, Inc.
 CONTACT Robert Hull
 ADDRESS P.O. Box 9013
 CITY San Dimas, CA 91773
 TELEPHONE 714-5990-3200

MODEL	4-317	RADIATION-RESISTANT	Yes
DIAMETER	0.75 in.	WITHSTAND CAUSTIC	
LENGTH	0.79 in.	ENVIRONMENT	No information
ACCURACY	±0.5% FSO	MATERIAL	No information
TEMPERATURE	600°F	INTRINSICALLY SAFE	No
TEMP. EFFECT	2%/100°F	FIT IN PRESENT TREE	Yes
PRICE			

NOTES: Only a few left; not being made anymore. Pressure range too high: 100-5000 psi.

PRESSURE TRANSDUCERS

NAME Industrial Sensors and Instruments, Inc.
 CONTACT Bud Dublin
 ADDRESS 308 Texas Ave., Suite 104
 CITY Round Rock, TX 78664
 TELEPHONE 512-255-3790

MODEL	Custom	RADIATION-RESISTANT	Custom
DIAMETER	in.	WITHSTAND CAUSTIC	
LENGTH	in.	ENVIRONMENT	Custom
ACCURACY	±0.1% FSO	MATERIAL	Custom
TEMPERATURE	200°F	INTRINSICALLY SAFE	Yes
TEMP. EFFECT	0.1%/100°F	FIT IN PRESENT TREE	Custom
PRICE			

NOTES: Electronics separate from transducer. Have expertise to design intrinsically safe transducers as well as radiation-hardened electronics in a corrosion-resistant package. Seem knowledgeable in this area. Custom transducers for the oil industry.

NAME ISR Transducer Div.
 CONTACT
 ADDRESS 17150 Newhope St., Suite 1002
 CITY Fountain Valley, CA 92780
 TELEPHONE 714-751-3266

MODEL	TH-LVA-LD	RADIATION-RESISTANT	No
DIAMETER	1.5 in.	WITHSTAND CAUSTIC	
LENGTH	3.5+ in.	ENVIRONMENT	Maybe
ACCURACY	±0.5% FSO	MATERIAL	17-4 pH s.s.
TEMPERATURE	150°F	INTRINSICALLY SAFE	
TEMP. EFFECT	0.45%/100°F	FIT IN PRESENT TREE	Yes
PRICE	\$630		

NOTES: Electronics separated from transducer.

PRESSURE TRANSDUCERS

NAME Kaman Instrumentation Corp.
CONTACT Darvin Kaelberer
ADDRESS 1500 Garden of the Gods Road
CITY Colorado Springs, CO 80933
TELEPHONE 719-599-1500

MODEL	KP-2025	RADIATION-RESISTANT	Yes
DIAMETER	0.83 in.	WITHSTAND CAUSTIC	
LENGTH	1.53 in.	ENVIRONMENT	Yes
ACCURACY	±2% FSO	MATERIAL	Inconel
TEMPERATURE	500°F	INTRINSICALLY SAFE	No
TEMP. EFFECT	4%-8%/100°F	FIT IN PRESENT TREE	Yes
PRICE			

NOTES

NAME Keller PSI
CONTACT Craig Spangler
ADDRESS 503 Vista Bella, Suite 11
CITY Oceanside, CA 92507
TELEPHONE 619-967-6066

MODEL	200S	RADIATION-RESISTANT	No
DIAMETER	1.0 in.	WITHSTAND CAUSTIC	
LENGTH	3.78 in.	ENVIRONMENT	Yes
ACCURACY	±0.5% FSO	MATERIAL	316 s.s.
TEMPERATURE	122°F	INTRINSICALLY SAFE	No
TEMP. EFFECT	2.8%/100°F	FIT IN PRESENT TREE	Yes
PRICE			

NOTES

PRESSURE TRANSDUCERS

NAME Kistler
CONTACT Kathy
ADDRESS 10201 Willows Road NE
CITY Redmond, WA 98073
TELEPHONE 206-881-8000

MODEL	Many	RADIATION-RESISTANT	No
DIAMETER	in.	WITHSTAND CAUSTIC	
LENGTH	in.	ENVIRONMENT	No information
ACCURACY	± % FSO	MATERIAL	No information
TEMPERATURE	°F	INTRINSICALLY SAFE	No information
TEMP. EFFECT	%/100°F	FIT IN PRESENT TREE	No information
PRICE			

NOTES: Specialize in Piezoelectric Pressure and Force Transducers and Accelerometers. Sonic sensor information was for harsh environments.

NAME Kulite
CONTACT
ADDRESS One Willow Tree Road
CITY Leona, NJ 07605
TELEPHONE 210-461-0990

MODEL	Several	RADIATION-RESISTANT	No information
DIAMETER	in.	WITHSTAND CAUSTIC	
LENGTH	in.	ENVIRONMENT	No information
ACCURACY	± % FSO	MATERIAL	No information
TEMPERATURE	°F	INTRINSICALLY SAFE	No information
TEMP. EFFECT	%/100°F	FIT IN PRESENT TREE	No information
PRICE			

NOTES: Miniature transducers. Have had reliability problems with them in the past. Not recommended for this application.

PRESSURE TRANSDUCERS

NAME Lucas Schaevitz, Inc.
 CONTACT
 ADDRESS 7905 N. Route 130
 CITY Pennsauken, NJ 08110-1489
 TELEPHONE 609-662-8000

MODEL	P1000	RADIATION-RESISTANT	No
DIAMETER	in.	WITHSTAND CAUSTIC	
LENGTH	in.	ENVIRONMENT	Yes
ACCURACY	±0.5% FSO	MATERIAL	
TEMPERATURE	°F	INTRINSICALLY SAFE	Yes
TEMP. EFFECT	%/100°F	FIT IN PRESENT TREE	No information
PRICE			

NOTES: They make radiation-tolerant LVDT's and intrinsically safe/corrosion-resistant transducers, but they do not combine the technologies and do not want to.

NAME Statham (Mark IV Transducer Corp.)
 CONTACT
 ADDRESS 2230 Statham Blvd.
 CITY Oxnard, CA 93033
 TELEPHONE 805-487-8511

MODEL	PG3018	RADIATION-RESISTANT	Yes
DIAMETER	2.7 in.	WITHSTAND CAUSTIC	
LENGTH	6.11 in.	ENVIRONMENT	Yes
ACCURACY	±0.25% FSO	MATERIAL	316 and Hast.
TEMPERATURE	180°F	INTRINSICALLY SAFE	No
TEMP. EFFECT	1%/100°F	FIT IN PRESENT TREE	No
PRICE	\$1,800-\$2,000		

NOTES: Specialize in diaphragm fluid-filled pressure, delta-P transducers and densitometers.

PRESSURE TRANSDUCERS

NAME Micron Instruments
 CONTACT
 ADDRESS 4509 Runway Street
 CITY Simi Valley, CA 93063
 TELEPHONE 805-522-4676

MODEL	MP40 Series	RADIATION-RESISTANT	No
DIAMETER	0.494 in.	WITHSTAND CAUSTIC	
LENGTH	1.75 in.	ENVIRONMENT	Yes
ACCURACY	$\pm 0.25\%$ FSO	MATERIAL	316 SS
TEMPERATURE	130 °F	INTRINSICALLY SAFE	No
TEMP. EFFECT	$\pm 3\%/100^\circ\text{F}$	FIT IN PRESENT TREE	Yes
PRICE	\$165		

NOTES: Epoxy will not withstand radiation. Lowest standard transducer is 25 psi; nonstandard is 15 psi.

NAME Motorola Semiconductor
 CONTACT
 ADDRESS P.O. Box 20912
 CITY Phoenix, AZ 85036
 TELEPHONE

MODEL	Many	RADIATION-RESISTANT	No
DIAMETER	in.	WITHSTAND CAUSTIC	
LENGTH	in.	ENVIRONMENT	No
ACCURACY	$\pm$ % FSO	MATERIAL	Si., plastic
TEMPERATURE	°F	INTRINSICALLY SAFE	No information
TEMP. EFFECT	%/100°F	FIT IN PRESENT TREE	No information
PRICE			

NOTES: Specialize in miniature integrated circuit sensors.

PRESSURE TRANSDUCERS

NAME Paine Corporation
CONTACT Steve Evans
ADDRESS 2401 S. Bayview Street
CITY Seattle, WA 98144
TELEPHONE 206-329-8600

MODEL	Many	RADIATION-RESISTANT	Yes
DIAMETER	in.	WITHSTAND CAUSTIC	
LENGTH	in.	ENVIRONMENT	No information
ACCURACY	± % FSO	MATERIAL	No information
TEMPERATURE	°F	INTRINSICALLY SAFE	Yes
TEMP. EFFECT	%/100°F	FIT IN PRESENT TREE	No information
PRICE			

NOTES: They make transducers which are radiation-hardened and are familiar with intrinsic safety requirements, but they would have to do some development to achieve a low enough pressure range for this application. They seemed willing to consider this.

NAME Sensotec
CONTACT Kevin
ADDRESS 1200 Chesapeake Ave.
CITY Columbus, OH 43212
TELEPHONE 800-848-6564

MODEL	TJE	RADIATION-RESISTANT	
DIAMETER	2.5 in.	WITHSTAND CAUSTIC	
LENGTH	2.5 in.	ENVIRONMENT	No
ACCURACY	±0.5% FSO	MATERIAL	17-4 pH s.s.
TEMPERATURE	160°F	INTRINSICALLY SAFE	Yes
TEMP. EFFECT	1%/100°F	FIT IN PRESENT TREE	No
PRICE			

NOTES: Electronics can be located 100 feet from the transducer. Intrinsically safe model available, but no information. Delta-P model has been used in the past with no problems.

PRESSURE TRANSDUCERS

NAME Sensotron
CONTACT Jan Matthews
ADDRESS 5881 Engineer Drive
CITY Huntington Beach, CA 92649
TELEPHONE 714-893-1514

MODEL	SEN	RADIATION-RESISTANT	Yes
DIAMETER	1 in.	WITHSTAND CAUSTIC	
LENGTH	3.5 in.	ENVIRONMENT	No
ACCURACY	±0.25% FSO	MATERIAL	S.S., Sapphire
TEMPERATURE	300°F	INTRINSICALLY SAFE	Yes
TEMP. EFFECT	1.75%/100°F	FIT IN PRESENT TREE	Yes
PRICE			

NOTES: This is the type of transducer used previously in the 101-SY waste tank. Electronics separate. Company flexible in customizing for customer's needs. Sapphire not take environment.

NAME Soltec Corporation
CONTACT Lonnie Lucas
ADDRESS 12977 Arroya Street
CITY San Fernando, CA 91340
TELEPHONE 818-365-7839

MODEL	PG-U	RADIATION-RESISTANT	No
DIAMETER	2.48 in.	WITHSTAND CAUSTIC	
LENGTH	4.09 in.	ENVIRONMENT	Maybe
ACCURACY	±0.3% FSO	MATERIAL	306 S.S.
TEMPERATURE	140°F	INTRINSICALLY SAFE	No
TEMP. EFFECT	1.11%/100°F	FIT IN PRESENT TREE	No
PRICE	\$880		

NOTES: 28.4 psi is smallest range.

PRESSURE TRANSDUCERS

NAME Statham (Mark IV Transducer Corp.)
CONTACT
ADDRESS 2230 Statham Blvd.
CITY Oxnard, CA 93033
TELEPHONE 805-487-8511

MODEL	P83018	RADIATION-RESISTANT	Yes
DIAMETER	2.7 in.	WITHSTAND CAUSTIC	
LENGTH	6.11 in.	ENVIRONMENT	Yes
ACCURACY	$\pm 0.25\%$ FSO	MATERIAL	316 and Hast.
TEMPERATURE	180°F	INTRINSICALLY SAFE	No
TEMP. EFFECT	1%/100°F	FIT IN PRESENT TREE	No
PRICE	\$1,800-\$2,200		

NOTES: Specializes in diaphragm fluid-filled pressure delta-P transducers and densitometers.

NAME Taber Industries
CONTACT Kenneth Lenz
ADDRESS 455 Bryant Street
CITY North Tonawanda, NY 14120
TELEPHONE 716-694-4000

MODEL	2801	RADIATION-RESISTANT	No
DIAMETER	in.	WITHSTAND CAUSTIC	
LENGTH	in.	ENVIRONMENT	Maybe
ACCURACY	$\pm 0.25\%$ FSO	MATERIAL	S.S.
TEMPERATURE	170°F	INTRINSICALLY SAFE	Yes
TEMP. EFFECT	%/100°F	FIT IN PRESENT TREE	No information
PRICE			

NOTES

PRESSURE TRANSDUCERS

NAME Validyne
CONTACT Gene Parberry
ADDRESS 8626 Wilbur Avenue
CITY Northridge, CA 91324
TELEPHONE 800-423-5851

MODEL P307
DIAMETER 2.4 in.
LENGTH 6 in.
ACCURACY $\pm 0.25\%$ FSO
TEMPERATURE 160°F
TEMP. EFFECT 2%/100°F
PRICE

RADIATION-RESISTANT No
WITHSTAND CAUSTIC
ENVIRONMENT No
MATERIAL Plastic
INTRINSICALLY SAFE No
FIT IN PRESENT TREE No

NOTES

NAME Viatran Corporation
CONTACT Bob Joslin
ADDRESS 300 Industrial Drive
CITY Grand Island, NY 14072
TELEPHONE 716-773-1700

MODEL 314
DIAMETER 1 in.
LENGTH 8 in.
ACCURACY $\pm 0.3\%$ FSO
TEMPERATURE 86 °F
TEMP. EFFECT 1.5%/100°F
PRICE

RADIATION-RESISTANT No
WITHSTAND CAUSTIC
ENVIRONMENT Yes
MATERIAL 316 s.s.
INTRINSICALLY SAFE No
FIT IN PRESENT TREE No

NOTES

APPENDIX B

DATA SHEETS

APPENDIX B

DATA SHEETS

TABLE B1. Measured Output of Kaman Transducer in Water at 72°F

RUN 1		RUN 2	
Measured Level (in.)	Transducer Output (mv)	Measured Level (in.)	Transducer Output (mv)
49.06	807.5	51.00	811.6
47.00	803.5	49.00	807.7
45.00	800.1	47.00	804.3
43.00	796.3	45.00	800.3
41.00	792.8	43.00	796.6
39.06	789.2	40.94	792.9
37.00	785.7	39.00	789.5
35.00	781.6	36.94	785.8
32.00	777.8	35.00	782.5
31.00	774.5	33.00	778.8
28.94	771.2	30.94	774.1
27.00	767.6	29.06	771.1
24.94	764.0	27.00	766.7
22.94	760.6	25.00	763.3
21.00	757.4	23.00	759.9
19.00	750.4	21.00	756.5
17.00	750.4	19.00	753.3
15.00	746.8	17.06	749.9
13.06	743.3	15.00	746.4
11.00	739.6	13.00	742.9
9.06	736.1	11.00	739.4
7.06	732.6	9.00	735.4
5.06	728.9	7.00	731.9
3.00	725.3	4.94	728.3
		2.94	724.9

Test conducted on the afternoon of November 15, 1993. Barometric pressure was 29.087 inches of Mercury.

TABLE B2. Measured Output of Kaman Transducer in Water at 72°F Two Days Later

RUN 1		RUN 2	
Measured Level (in.)	Transducer Output (mv)	Measured Level (in.)	Transducer Output (mv)
51.00	814.9	51.06	815.4
48.94	811.3	49.00	811.8
46.87	807.5	47.00	808.1
45.00	804.5	45.00	804.6
43.00	800.8	43.00	800.9
41.00	797.2	40.94	797.5
39.00	793.5	38.94	793.6
37.00	789.9	37.00	790.3
35.00	786.3	35.00	786.6
33.00	782.7	33.06	783.0
31.12	779.2	31.00	779.4
29.00	775.4	29.00	775.7
27.00	771.6	27.06	772.0
25.00	768.0	25.00	768.2
23.00	764.3	23.00	764.4
21.00	761.0	21.00	760.9
18.94	757.1	19.00	757.4
17.00	753.8	16.94	753.9
14.94	750.0	14.94	750.4
12.94	746.6	13.00	747.0
11.00	743.2	11.00	743.3
9.00	739.7	9.00	739.8
7.00	735.9	7.00	736.2
5.00	732.4	5.00	732.6
3.00	728.8	2.94	729.0

Test conducted on the afternoon of November 17, 1993. Barometric pressure was 29.187 inches of Mercury.

TABLE B3. Measured Output of Kaman Transducer in Water at Approximately 100°F

RUN 1 (92°F)		RUN 2 (89°F)	
Measured Level (in.)	Transducer Output (mv)	Measured Level (in.)	Transducer Output (mv)
51.00	818.0	51.94	819.0
48.87	813.9	49.00	816.5
47.06	810.7	47.00	812.8
45.00	807.5	45.00	808.7
42.94	803.7	42.94	805.1
41.00	800.5	41.00	801.4
38.87	796.7	38.94	797.9
37.00	793.6	37.00	794.4
35.00	790.1	35.00	790.9
33.00	786.7	33.00	787.3
31.00	783.1	31.00	783.9
29.00	779.7	29.00	780.3
27.00	775.9	27.00	776.5
24.94	772.2	25.00	773.1
23.00	768.8	23.06	769.5
21.00	765.6	21.00	765.8
19.00	762.1	19.00	762.3
17.00	758.2	17.00	758.6
15.00	754.9	15.00	755.1
12.94	751.2	13.00	751.4
11.00	747.6	11.00	748.0
9.00	744.1	9.00	744.0
7.00	740.5	7.00	740.7
5.00	736.6	5.00	737.2
3.00	732.9	3.00	733.8

Test conducted on the morning of November 16, 1993. Barometric pressure was 29.322 inches of Mercury.

TABLE B4. Measured Output of Kaman Transducer in Water at Approximately 130°F

RUN 1 (125°F)		RUN 2 (114°F)	
Measured Level (in.)	Transducer Output (mv)	Measured Level (in.)	Transducer Output (mv)
48.94	816.2	48.50	814.2
47.00	811.7	46.94	811.3
45.00	808.1	45.00	808.0
43.00	805.1	42.81	803.9
41.94	801.6	41.06	800.8
39.00	798.5	39.00	797.2
36.94	794.6	37.00	793.6
34.94	791.3	35.00	789.9
32.75	787.2	33.00	786.5
31.06	784.7	31.00	782.9
28.81	780.8	28.75	779.1
27.00	777.5	27.00	775.6
25.00	773.8	25.00	772.3
23.00	770.5	22.94	768.8
21.00	767.2	21.00	765.3
19.00	763.0	19.00	761.8
17.00	759.5	16.94	757.9
15.00	756.3	15.00	754.3
13.00	753.1	13.06	751.0
11.00	749.3	11.00	747.0
9.00	745.8	9.00	743.8
7.00	742.1	7.00	740.3
5.00	738.5	5.00	736.4
3.00	734.9	3.00	733.1

Test conducted on the afternoon of November 17, 1993. Barometric pressure was 29.186 inches of Mercury.

TABLE B5. Stability of Kaman Transducer

<u>Date</u>	<u>Time</u>	<u>Level (in.)</u>	<u>Output (mv)</u>	<u>Barometric Pressure (in. of Hg)</u>
11/15/93	15:47	2.94	724.9	29.087
11/16/93	07:53		731.1	29.322
11/17/93	10:57	51.00	815.3	29.228
	11:35		815.3	
	12:38		814.9	

A. In Water

<u>Date</u>	<u>Time</u>	<u>Level (in.)</u>	<u>Output (mv)</u>	<u>Barometric Pressure (in. of Hg)</u>
11/17/93	15:28	5.44	737.8	29.186
11/18/93	07:43		745.6	29.534
	08:35		746.1	
	09:11		746.6	
	10:00		745.3	
11/18/93	12:51	6.31	749.7	
	12:58		750.1	
	13:44	6.37	750.7	
	14:45	6.44	750.7	29.573
	15:35		750.8	
11/19/93	07:39		752.7	29.660
	09:12		752.9	
	10:35		752.6	
	12:59		751.2	

B. In Simulant

TABLE B6. Measured Output of Kaman Transducer in Simulant at Approximately 71°F

RUN 1		RUN 2	
Measured Level (in.)	Transducer Output (mv)	Measured Level (in.)	Transducer Output (mv)
51.00	868.6	51.00	868.4
48.94	863.1	49.00	862.8
46.44	856.0	46.81	856.7
45.00	851.8	44.94	851.3
42.62	845.9	43.06	846.1
41.00	840.5	40.88	840.0
39.00	835.0	39.00	834.5
36.69	828.4	37.00	829.0
35.06	823.6	35.00	823.3
32.94	817.6	32.50	816.1
30.62	812.0	30.94	811.9
29.06	806.9	29.06	806.4
27.00	801.0	27.00	800.0
25.00	795.2	24.88	794.4
23.00	789.4	23.06	784.1
21.00	784.0	21.00	783.3
19.00	778.3	18.94	777.3
17.00	772.3	16.94	771.6
15.06	766.8	15.00	766.1
13.00	761.6	13.00	760.2
11.00	755.4	11.00	754.5
9.00	749.0	9.00	748.9
7.00	742.9	7.00	742.8
5.00	736.9	5.00	736.4
3.00	731.8	3.00	730.9

Test conducted on the afternoon of November 17, 1993. Barometric pressure was 29.186 inches of Mercury.

TABLE B7. Measured Output of Kaman Transducer in Simulant At Approximately 100°F

RUN 1 (100°F)		RUN 2 (98°F)	
Measured Level (in.)	Transducer Output (mv)	Measured Level (in.)	Transducer Output (mv)
50.88	878.0	51.00	878.2
49.06	873.3	49.06	872.8
47.00	867.1	47.00	866.1
45.00	861.9	45.00	860.7
43.00	860.9	42.81	855.4
40.94	851.9	41.00	849.8
39.00	845.9	38.94	844.3
37.00	839.4	37.00	838.7
35.03	833.5	35.00	833.2
33.00	827.5	32.62	827.9
31.00	821.9	31.00	822.9
29.00	816.1		
26.94	810.5		
24.75	804.1		
23.06	799.5	23.00	799.4
21.00	793.8	20.95	793.7
18.94	788.6	19.00	788.0
16.88	782.3	16.94	781.9
14.88	772.2	14.94	776.5
13.00	771.2	13.00	771.2
11.06	766.7	10.88	766.0
9.00	761.3	8.94	760.9
7.06	756.9	7.00	758.5
4.88	754.7	5.03	753.0
3.00	748.3	3.00	743.8

Test conducted on the morning of November 18, 1993. Barometric pressure was 29.573 inches of Mercury.

TABLE B8. Measured Output of Kaman Transducer in Simulant At Approximately 130°F

RUN 1 (125°F)		RUN 2 (114°F)	
Measured Level (in.)	Transducer Output (mv)	Measured Level (in.)	Transducer Output (mv)
50.94	881.7	50.94	880.6
49.00	873.8	49.00	876.1
46.88	870.7	46.94	870.2
45.00	866.1	44.94	865.0
42.88	858.5	43.00	859.5
41.00	854.2	41.00	853.8
38.94	848.3	38.94	849.6
36.94	843.8	36.94	843.3
35.00	839.3	35.00	840.9
32.81	832.5	32.94	834.4
31.06	827.9	31.00	826.5
28.88	821.6	28.94	821.9
26.88	816.5	27.00	815.0
24.88	811.5	25.00	810.0
22.88	805.7	23.00	804.5
20.88	800.7	21.00	797.2
18.94	794.7	18.94	791.6
16.88	788.6	17.00	785.0
14.88	782.8	15.00	778.2
13.00	777.5	13.06	774.9
11.00	771.7	11.00	770.2
8.88	766.6	9.00	763.1
6.88	761.2	6.94	757.4
5.00	755.7	5.00	756.0
3.00	754.4	3.00	749.0

Test conducted on the afternoon of November 19, 1993. Barometric pressure was 29.660 in. of Mercury.

TABLE B9. Measured Output of Kaman Transducer in Water At Approximately 72°F After Exposure to Gamma Radiation for an Equivalent of Five Years at 1000 R/hr.

RUN 1		RUN 2	
Measured Level (in.)	Transducer Output (mv)	Measured Level (in.)	Transducer Output (mv)
24.00	771	24.00	770
22.00	767	22.05	767
20.00	764	20.00	763
18.00	760	18.00	760
16.00	756	16.00	756
14.05	753	14.05	753
12.00	749	12.00	749
10.00	746	10.00	745
8.00	742	8.00	741
6.00	738	6.00	738
4.00	734	4.00	734
2.00	731	2.00	730

Test conducted on the morning of March 2, 1994. Barometric pressure was 29.48 inches of Mercury.

TABLE B10. Measured Output of VEGA Transducer in Water at Approximately 72°F

RUN 1		RUN 2 (3)	
Measured Level (in.)	Transducer Output (ma)	Measured Level (in.)	Transducer Output (ma)
49.94	9.934	50.18	6.890
47.94	9.827	49.94	6.730
46.00	9.720	46.06	6.622
44.00	9.666	44.00	6.515
42.06	9.613	42.00	6.355
40.00	9.454	40.00	6.249
38.06	9.293	38.00	6.088
36.00	9.133	36.06	5.981
34.06	9.025	34.00	5.821
32.00	8.866	32.00	5.714(4)
30.00	8.759	30.00	5.554
28.00	8.652	28.00	5.447
26.00	8.594	26.00	5.340
23.94	8.545(1)	24.00	5.234(5)
22.00	8.812	22.00	5.341
20.00	9.080	20.00	5.234
18.00	8.919	18.00	5.127
16.00	8.812	16.00	5.019
14.00	8.652	14.00	4.913
12.00	8.599	12.00	4.806(6)
9.94	8.493	9.96	5.393
7.94	8.332	8.00	5.073
6.00	8.225	6.00	4.966
4.00	8.118	3.94	4.806
2.00	8.011	1.94	4.647

Test conducted on the morning of January 17, 1994. Barometric pressure was 29.84 in. of Mercury.

Notes:

1. Output current jumped to 8.652 ma after waiting approximately two minutes.
2. Output current jumped to 9.186 ma when system is disconnected and reconnected.
3. Operating parameters readjusted because current output jumped 2.2 ma at approximately 50 inches.
4. Output current changed to 5.660 ma in less than a minute.
5. Output current varied from 5.288-5.447 ma in two minutes.
6. Output current rose to 5.501 ma in 46 minutes, then dropped to 5.393 ma eight minutes later.

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