

**" EXPERIENCE WITH CABLE-SENSOR-TYPE LEAK DETECTION
SYSTEMS FOR ABOVEGROUND STORAGE TANKS "**

**By
Rudy S. Hogg
Senior Project Manager
Kinder Morgan Energy Partners, L. P.
Orange, California**

Presented at the

**NINETEENTH ANNUAL
ILTA INTERNATIONAL OPERATING
CONFERENCE**

**Adams Mark Hotel
Houston, TX**

June 14-17, 1999

For the Conference Session Entitled:

" IN PURSUIT OF STOPPING LEAKS AND SPILLS #2 "

" EXPERIENCE WITH CABLE-SENSOR-TYPE LEAK DETECTION SYSTEMS FOR ABOVEGROUND STORAGE TANKS "

Rudy S. Hogg
Senior Project Manager
Kinder Morgan Energy Partners, L. P.

PERSONAL PROFILE

Mr. Hogg has a Bachelor of Science Degree in Electrical Engineering from Colorado State University. He had early experience in water and power with the Bureau of Reclamation, followed by experience in SCADA system design with Morrison-Knudsen Engineers. The last nine years of experience has been in petroleum transportation and storage with Chevron Pipe Line Co. and Kinder Morgan Energy Partners, L.P. (formerly Santa Fe Pacific Pipelines). He is currently a Senior Project Manager handling multidiscipline construction projects for refined product pipelines, pumping stations, storage facilities, and loading terminals. One key element of his current assignment is to handle all leak detection installations at storage and terminal facilities in the Pacific Operations Area of Kinder Morgan.

PRESENTATION ABSTRACT

The paper discusses experiences of Kinder Morgan Energy Partners in developing a cost effective leak detection program for implementation on aboveground storage tanks. Discussion includes leak detection technologies evaluated and reasons for the selection of a cable-type sensor system. The leak detection system that was selected will be described, along with the advantages, disadvantages, and costs. Methods for installing 2-inch screened PVC pipe under existing tanks will be discussed, including the use of impact and rotary-type horizontal drilling. Some of the problems encountered will be identified, as well as the criteria for location and spacing of the 2-inch PVC sensor pipes. Background data will be provided on leakage plume migration studies that were performed during the evaluation process.

" EXPERIENCE WITH CABLE-SENSOR-TYPE LEAK DETECTION SYSTEMS FOR ABOVEGROUND STORAGE TANKS "

By
Rudy S. Hogg
Kinder Morgan Energy Partners, L. P.

1.0 INTRODUCTION

1.1 The Need for a Responsive Leak Detection System

Kinder Morgan has several hundred aboveground storage tanks in service in the Midwest and Western parts of the U.S. Although there is an ongoing program to inspect, repair, and protect all of the tanks from conditions that could cause a leak, there are always the unknown conditions that can initiate a leak without warning. Historically, the primary method of leak detection has been visual. At manned stations, the policy has been to walk the tank farm every 12 hours. At unmanned stations, the walk occurs less frequently, usually once per week. Experience has shown that a visual indication of a tank bottom leak may not occur for months after a leak has started. Time is the enemy in a slow leak scenario because of the vertical migration that inevitably occurs. Cleanup costs and out of service time tends to expand geometrically as the depth of vertical migration increases. For these reasons, Kinder Morgan decided that a more responsive leak detection method should be pursued.

1.2 Soil and Hypothetical Leakage Studies at San Jose

As a means to define leakage migration rates, in 1995 Kinder Morgan authorized a soils engineering firm to take soil samples and perform detailed permeability studies at the San Jose California Terminal. This terminal is representative of the tank foundation designs that have been used throughout the company for many years. The typical foundation design includes a 3-foot layer of recompacted native or imported clay-laden material, followed by a 1-foot layer of ¾-inch gravel (road base material), followed by a 3-inch layer of oiled sand that the tank floor plates rest upon. A concrete ring wall is typically not used in the foundation design.

The study included taking core samples through the outer edge of several tank foundations, which were subjected to Conductivity and Total Organic Carbon Tests to determine relative permeability for the gravel layer and clay / silt layer. A hypothetical small 1-gallon per hour gasoline leak was defined for study from the center of a small (25-foot diameter) tank and a large (125-foot diameter) tank. The study concluded that the leak would travel in the underlying gravel layer horizontally for a distance of 14.3 feet in 30 days, 35 feet in 180 days, and 62.5 feet in 575 days, as shown in Figure 1. This hypothetical leak could be visible at the outer edge of a small tank in one month, but would not be visible on a large tank for over a year and a half. At the same time, the same leak scenario could cause vertical migration into the underlying clay / silt layer of 0.3 feet in 30 days, 1.9 feet in 180 days and 6 feet in 575 days.

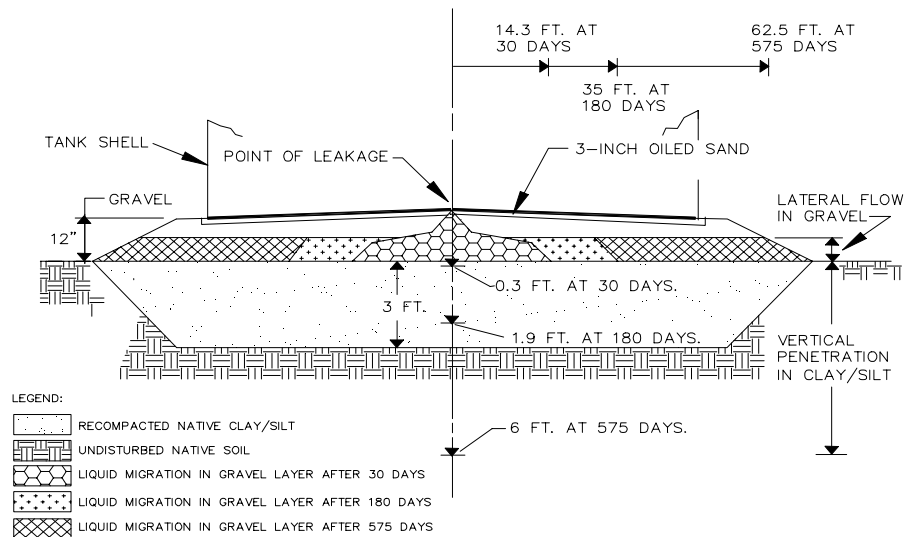


Figure 1 – Hydrocarbon Migration in Tank Foundation

This study helped to confirm that the gravel-over-clay layering foundation design is a good approach for limiting vertical migration; however, it also confirmed that visual monitoring only is not the optimum form of leak detection. The study was useful in bringing Kinder Morgan and the San Jose Fire Department together in defining a preferred location for leak sensor pipes that needed to be installed

under tanks for leak sensing. It was determined that perforated (screened) leak sensor piping should be located at the base of the gravel layer and no more than 30 feet apart. That is, a leak will need to travel no more than 15 feet before it reaches a sensor pipe. This design has become a standard at Kinder Morgan and is developing into a standard for regulatory agencies across the country.

1.3 Evaluating Leak Detection Technologies

Prior to installation of any leak detection system, Kinder Morgan evaluated five types of technologies that were available in 1996. All of the technologies evaluated would provide a continuous monitoring of perforated pipes installed beneath tanks. Technologies that provide a periodic or one-time test of tank integrity were not considered, because continuous monitoring was mandatory. The following types of technologies were evaluated:

- 1) Vapor Sniffer – This technology uses a centrally-located vapor sniffer that sequentially sniffs long lengths of small bore tubing that runs to the sensor piping under each tank.
- 2) Fiber-Optic Vapor / Liquid Sensor – This technology uses a centrally-located electronic box and computer to monitor specially coated fiber-optic sensors that are located in the sensor piping under each tank.
- 3) Polymer Ribbon Sensor – This technology uses a centrally-located electronic box to monitor the resistance of special hydrocarbon-sensitive ribbons that are located in the sensor piping under each tank.
- 4) Coaxial Cable, Impedance-Based Sensor – This technology uses a centrally-located electronic box to monitor the impedance characteristic change of hydrocarbons soaking into the coaxial cables that are located in the sensor piping under each tank.
- 5) Cable Sensor- This technology uses a local flasher electronic box that monitors the open-closed status of a special hydrocarbon-sensitive cable that is located in the sensor piping under each tank. Each cable sensor is an independent system with its own battery-powered flasher unit.

1.4 Centralized Versus Non-Centralized Monitoring

Each technology evaluated had its advantages, disadvantages and associated costs, and each appeared to provide various levels of continuous monitoring for the presence of hydrocarbons. To be effective, each technology required the installation of sensing pipes beneath each tank to gain access to tank bottom leaks. One notable difference in the evaluations was that Item 5) Cable Sensor technology did not require centralized monitoring because each sensor cable had its own inexpensive battery-operated flasher unit that made it a stand-alone leak detection system. Use of this technology would avoid the installation of thousands of feet of conduit and cable for power and signals. The down side was that leak detection could not be centrally monitored by a SCADA system. At Kinder Morgan, each tank farm is walked at least every 12 hours for problem detection, so it was concluded that the flasher units could be monitored during each walk-through without a manpower impact. By accepting this monitoring technique, Kinder Morgan was able to save significant costs associated with centralized monitoring that would have been required for other technologies.

2.0 DESCRIPTION OF CABLE SENSOR SYSTEM

The cable sensor system consists of a hydrocarbon-sensitive cable connected to a battery-powered electronic flasher module that is mounted about 3 feet above the tank apron at one end of a 2-inch screened PVC pipe installed beneath the bottom of the tank, as shown in Figure 2.

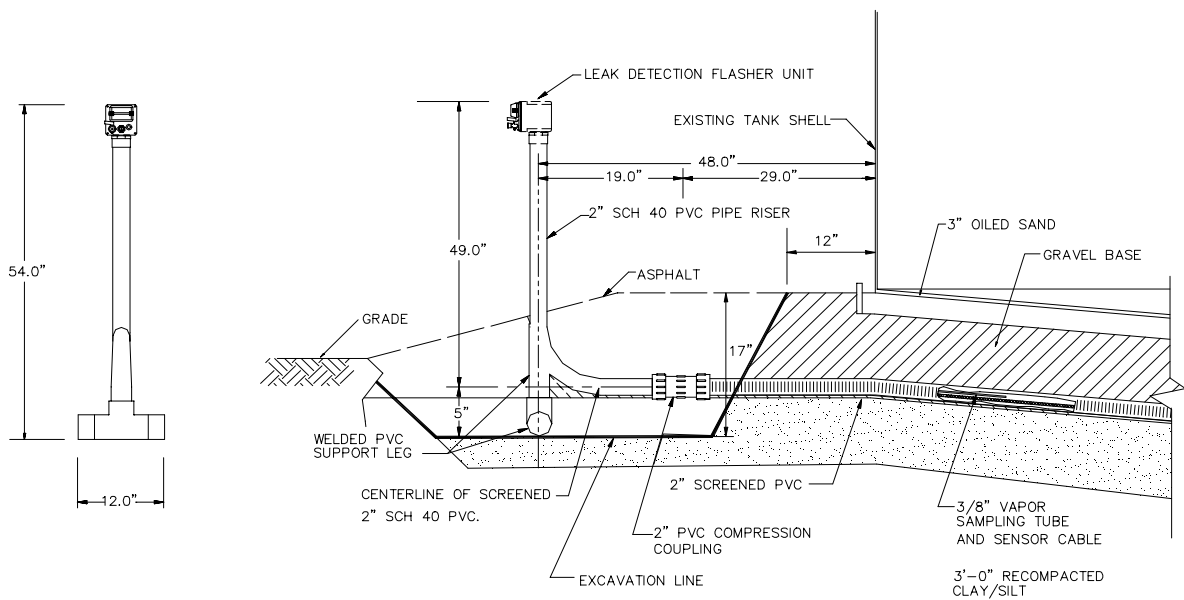


Figure 2 -- Leak Detection Flasher Unit Installation

2.1 Sensing Cable Design

The hydrocarbon-sensing cable, as shown in Figure 3, is about ¼ inch in diameter and consists of a set of seven wires twisted together, then covered with a hydrocarbon-sensing polymer, followed by an outer braid. Two of the wires are called electrodes and are coated with a special conductive polymer that will conduct with the outer polymer when activated by hydrocarbons. In the presence of hydrocarbons, the two electrodes act like a switch to activate the flasher module. Since the outer polymer will swell on contact with hydrocarbons, the outer braid is designed to force the polymer to swell inward to squeeze the two electrode wires tightly together to act as a solid contact closure to the flasher module. The remaining wires in the cable are not used in this application. After the cable is activated by hydrocarbons, it will need to be replaced.

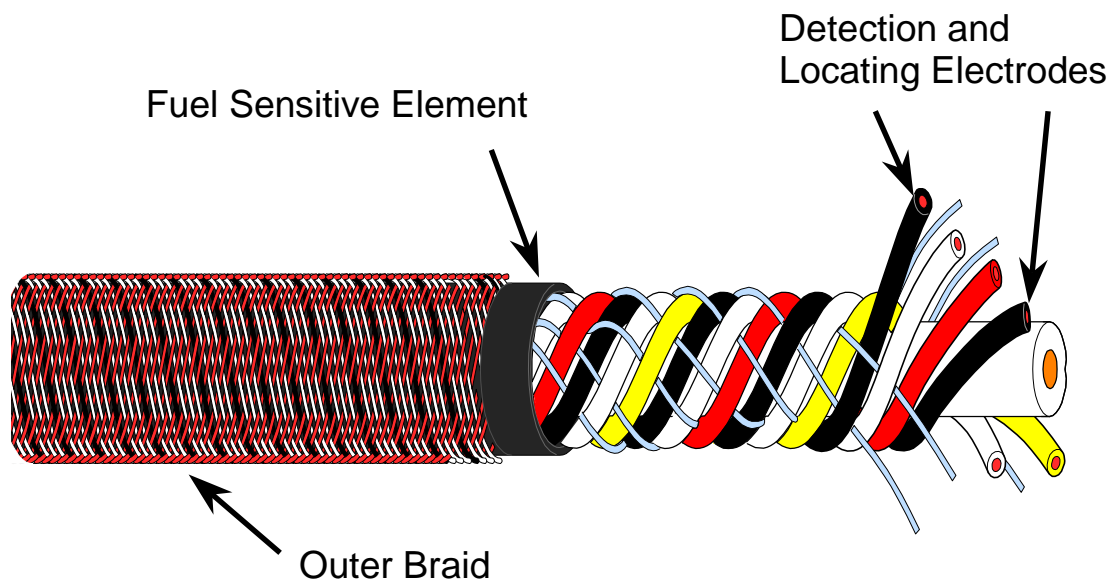


Figure 3 -- Hydrocarbon Sensing Cable

2.2 Flasher Unit Design

The flasher unit, as shown in Figure 4, consists of a small PVC NEMA 4X box with a strobe-like LED flasher, including compact sealed electronics, two AA alkaline batteries, a Push-to-Test button, and a vapor sampling port. When the cable senses hydrocarbons, the flasher will pulse at about one flash per second. The unit includes internal sensing circuitry to detect a "Low Battery" condition that will operate the flasher at a different pulse rate. The manufacturer claims the batteries will operate the unit for two years, but recommends replacement of batteries on an annual basis. The batteries are designed to operate the flasher continuously for up to two weeks after being activated by hydrocarbon detection. The 3-volt power source makes the unit safe for operation in NEC Class 1, Division 2 locations, as is typically the case in a tank farm. The vapor sampling port on the unit is attached to a 3/8-inch tube that extends for several feet under the tank to provide a quick sniffer verification of a leak condition after the flasher alarm goes off.



Figure 4 – Flasher Unit

3.0 INSTALLATION OF SENSOR PIPE

All tank leak detection technologies require some way to get access under the tank so that bottom leaks can be detected. Kinder Morgan has chosen to use 2-inch screened PVC rather than a smaller size, because it allows any available leak detection technology to be used and will double as an insertion path for a cathodic protection reference cell when needed. The “screened” pipe is basically Schedule 40 white PVC pipe with 20-mil slots cut laterally around the pipe every ¼ inch. Additionally, the pipe ends are threaded into each adjacent section to form a smooth coupling to simplify pulling the pipe into the 2-inch bored hole. The screened PVC pipe is usually installed in a parallel configuration, as shown in Figure 5, with the pipe extending beyond the tank shell by 3 to 5 feet on each side. The target depth is 12 to 15 inches below the bottom at the outer shell. For cone-up tank bottoms, the pipe can be installed level across the tank. For cone-down tank bottoms, the drill operator has the challenge of maintaining the bit approximately 12 to 15 inches from the tank bottom based on design information about how the bottom was originally built. The location of the bottom sump must always be defined and accommodated, since the sump usually extends below the level of the drilling.

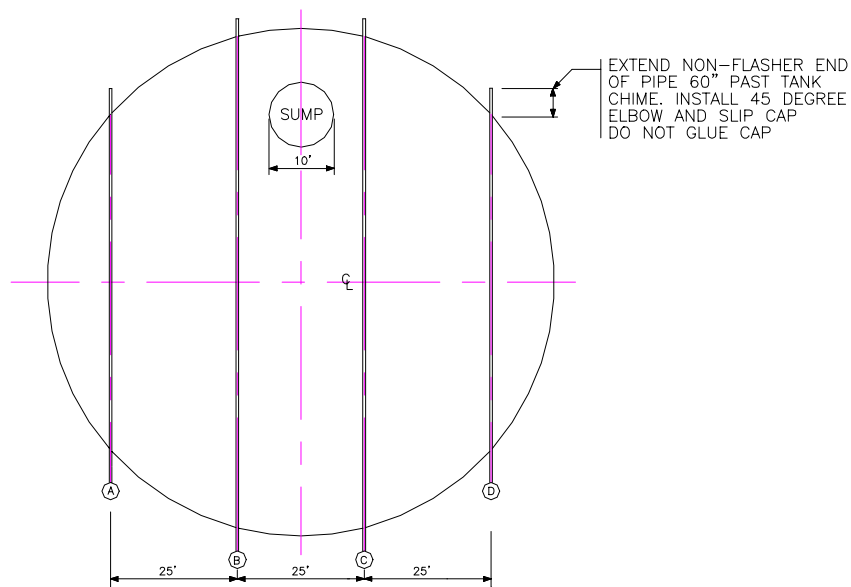


Figure 5 – Typical Spacing for 100' Diameter Tanks

3.1 Impact Drilling Method

Kinder Morgan has used both impact and rotary methods of horizontal drilling for installation of the 2-inch screened PVC pipe. The impact method uses an air-driven hammering mechanism to drive the drill rod and bit through the tank foundation material. This method uses a wedge-shaped bit that includes a differential pressure sensor in the bit head to determine depth for guidance purposes. The elevation of the bit is controlled by rotating the wedge from the up to down direction and vice versa. Control in the vertical direction is very good (plus or minus one inch). Control of drift in the lateral direction is limited and can be one to two feet away from the target when it reaches the far side of the tank. This method pulls the PVC pipe into the bore hole behind the bit as it inches forward. The impact method is relatively slow and labor intensive (not automated), plus it is about as noisy as a jackhammer. This boring method has an advantage that it is operated completely dry; no water is needed to assist or

cool the bit. This leaves the screened PVC pipe fairly clean and ready to accept a sensor cable as soon as the bit and drill rod are removed.

3.2 Rotary Drilling Method

The rotary method uses a commercially available horizontal drilling rig with semi-automated features. It uses a wedge-shaped bit that has an angle-of-tilt sensor in the bit head that is remotely monitored at the drill rig console. The drill rig pushes as it rotates the bit for a foot or so, then stops and the angle-of-tilt is checked. If correction is needed, the wedge is turned slowly to an up or down position and is pushed for a few inches without rotation, then is checked for angle-of-tilt again, and the cycle is repeated. This method uses a bit-locating transmitter box that is placed on the opposite side of the tank. The locator box also is used to indicate how far the bit is from the box and to allow for correction of lateral drift. The rotary method uses a high-pressure water stream in the bit to assist and cool the bit action. This causes the bore hole and lead-in trench to fill with mud from the drilling operation, but the small amount of mud created does not usually require special handling or removal. After the drill bit exits at the far side, a swivel pulling head is installed to pull the screened PVC pipe back into the bore hole as the drill rods are pulled back toward the drilling rig.

3.3 Screened PVC Pipe Installation for New Tanks

For new tank installations, Kinder Morgan completes the tank foundation up to the compacted gravel base, then uses a trencher to dig down to the base of the gravel to lay in the 2-inch screened PVC pipe. After the PVC is installed, the trench is then back filled with gravel and compacted. Attempting to install the PVC pipe before the gravel layer is placed has caused construction problems because of the vulnerability of the PVC under heavy construction equipment. The PVC is typically extended 3 to 5 feet outside of the tank shell, where a 45° coupling is attached followed by a short length of PVC and a slip-on cap. Protection of the PVC ends is a problem, so it is recommended to end the pipe

below grade and mark it with a stake so that the ends will not be damaged during tank construction.

4.0 WHAT ARE THE COSTS FOR CABLE SENSOR SYSTEMS ?

For estimating purposes, it should be assumed that two sensor pipes will be required for tanks up to 60 feet in diameter, three will be required for tanks up to 90 feet in diameter, and four will be required for tanks up to 120 feet in diameter. Drilling and installation of 2-inch PVC pipe under existing tanks has typically cost \$30.00 to \$40.00 per foot of installed pipe. Sensor cable typically costs \$13.00 per foot. The flasher units typically cost \$1,800.00 each. Installation of the sensor cable and flasher unit typically cost \$500.00 per unit. Engineering and Construction Management has typically cost \$30,000.00 to \$50,000.00 per project (i.e., 20 or more tanks). All of this translates to a cost of \$10,000 to \$35,000 per tank. For example, the cost for retrofitting leak detection on a 55-foot-diameter tank would be approximately \$12,000 and the cost for a 110-foot-diameter tank would be approximately \$30,000.

Although Kinder Morgan does not have any specific construction cost data on alternate technologies to compare to costs for the sensor cable systems, preliminary cost studies indicated the costs would be 50% to 100% higher for the alternate technologies. For some technologies, the cost of sensors and electronics was a major part of the cost difference, but for essentially all of the alternate technologies that involved a central monitoring point, the cost of trenching, conduit and cable from the tanks to the centralized monitoring location made a significant impact on the cost differential.

The costs listed above are the first-time installation costs. The other costs related to leak detection systems are maintenance costs, including calibration, sensor cleaning and battery replacement. Unanticipated but sometimes significant costs can result from false alarms generated by leak detection systems. These costs are usually man-hour costs associated with investigations, reporting paperwork, laboratory work and tank inspections. With the cable sensor system in use by Kinder Morgan there has been minimum maintenance, consisting primarily of annual battery replacement. The rather

low-tech system does not require calibration or sensor cleaning and has resulted in essentially no false alarms. To date, six alarms have been noted, one was a tank leak, four were underground valve flange leaks and one was caused by residual contamination from a previous leak. Analysis of other leak detection technologies has indicated that some have had hardware failures, some need frequent calibration and sensor cleaning and some have frequent false alarms.

5.0 EXPERIENCES AND PROBLEMS ENCOUNTERED

At Kinder Morgan, cable-type sensors have been installed on 67 tanks to date at 8 different sites, plus monitoring of 14 underground valves. Scheduled for implementation in 1999 are systems for 36 more tanks and 8 more underground valves. As a result of the implementation of these leak detection systems, the following experiences and tips are offered:

5.1 Drill Rig Space Requirement

Both impact and rotary drilling rigs will require approximately 20 feet of space in front of each drill hole. Typically if space is not available on one side of the tank, there is adequate space on the opposite side.

5.2 Maintaining Drilling Distance from Tank Bottom

Tank bottoms either cone up or cone down. For cone-up bottoms, a flat horizontal drilling path is suggested, but be sure to avoid the sump. For cone-down bottoms, the drill operator will need to know the degree of bottom slope to maintain a safe distance from the bottom. The designer will need to provide this information from existing tank records.

5.3 To Drill Through or Not

Initially the Kinder Morgan design did not require exiting the sensor pipes on the opposite side of the tank. The intent was to push the sensor cable into the pipe with an electrician's fish tape or long rod. Problems arose on several runs where the cable would not slide smoothly. In later installations the pipes were installed to exit on the far side and the cable was pulled in without problems or damage.

5.4 Taking Soil Samples

During early installations, soil samples were taken near the center of each bore. The samples were used to confirm that the bore was still in the gravel layer and not too far into the clay layer. Sampling was time consuming and was only done to satisfy a regulatory request. Samples were taken with a one-inch-diameter hollow sampler that was driven 18 inches in the direction of the bore and then withdrawn for evaluation.

5.5 Drilling Under Tanks with Existing Contamination

If old contamination is found when drilling under a tank, do not abandon hope. The sensor will only activate if there is standing liquid or high vapor concentrations. Kinder Morgan has successfully installed sensors under tanks where old leaks or spills had occurred several years before. However, if heavy rains bring water into the tank foundation area, an alarm may occur due to floating residual hydrocarbons. Generally, old contamination will not activate the sensor.

5.6 Bury or Conceal Opposite End of Sensor Pipe

When installing sensor pipes, take care to bury or conceal the far end of each pipe from damage. Experience has shown that any PVC that extends above tank apron will eventually become damaged. The suggested approach is to bury

the pipe end just below grade or conceal it in a flush-mounted fiberglass irrigation box.

5.7 Caution on Use of PVC Adhesive

Solvent-type PVC adhesive or the vapors from the adhesive will activate the sensor cable. If any of the adhesive is used for the sensor pipe installation, it must be allowed to air dry for at least 24 hours before coming in contact with the cable.

5.8 Use Care When Installing Sensor Cable

Care must be used when installing sensor cable to make sure it does not loop or kink. A kink will activate the cable, although it will recover when the kink is removed. Workers must be careful to have clean hands when handling the cable. Any oil that gets on the cable during installation will likely activate the cable.

5.9 Removal of Drilling Mud Prior to Cable Insertion

When using the rotary drilling method where water is used for drill bit cooling and lubrication, it will be necessary to flush and swab out most of the drilling mud from inside the PVC pipe prior to installation of the sensor cable. If this is not done, the mud will dry around the cable and make it difficult to remove later. Usually, pulling a rag through the pipe several times will be adequate to solve this problem.

5.10 Typical Drilling Times

For an 80,000 BBL tank (approximately 100 feet in diameter), the impact drilling method will typically require 6 hours per bore, except where extra-hard soil is encountered. The same bores can be completed in about half that time when the

rotary drilling method is used. For about 5% of the bores made by Kinder Morgan, extra-hard soil was encountered. For those cases, the time required was 3 to 4 times longer. In one case, a rotary rock bit had to be used for part of the bore.

5.11 Monitoring Tanks with Membranes or Double Bottoms

Although very few tanks in the Kinder Morgan system have external membranes or double bottoms, there is one of each type that has been fitted with cable-type leak detection systems. For these two cases, the membrane and the lower bottom were designed with a low spot or sump that is connected to a 3-inch pipe that extends to one side of the tank. A single sensor cable was used in each case to monitor the 3-inch pipe for tank leakage.

5.12 Monitoring Underground Valves and Flanges

A significant number of leak occurrences in the Kinder Morgan system have been from underground valves that include flanges and from stand-alone underground flanges. It is suggested that leak detection should be provided at all locations where underground flanges are in service. The suggested method is to install a “J” shaped section of 2-inch screened PVC pipe beneath the valve or flange with the flasher box mounted above ground.

5.13 Monitoring Interstitial Space in Double-Walled Underground Storage Tanks

The cable sensor systems have been used successfully for monitoring the interstitial space between the inner and outer wall of underground storage tanks, such as sump tanks and oily water separators.

5.14 Monitoring for Leakage in an Underground Manifold Area

Future plans include installation of cable sensors vertically into 2-inch PVC that will be installed vertically into the ground at frequent intervals (i.e., 10-foot spacing) within an underground manifold area. The sensor pipes will extend down approximately 20 feet to try to intercept leakage migration. Some problems are anticipated with this installation because of existing contamination and the likelihood of hydrocarbons floating on water that may occur during the rainy season. The technique to be used for installing the vertical screened PVC will be the "Hydro-Vac" method to avoid possible damage to underground pipes and conduits in the crowded manifold area.

6.0 SUMMARY AND CONCLUSIONS

After soil studies were conducted in 1995, Kinder Morgan concluded that a more responsive form of leak detection for aboveground storage tanks must be implemented to improve on the existing visual leak detection method. Several leak detection technologies were evaluated and a non-centralized cable sensor system was selected, in conjunction with installation of horizontally-drilled leak sensor pipes. Kinder Morgan now has 67 tanks and 14 valves under continuous monitoring by the selected cable sensor leak detection system. The systems have been installed at a cost of 50% to 100% less than the alternate technologies and there have been minimum maintenance and troubleshooting costs since the initial installation. One of the main compromises a user must accept in selecting the cable sensor technology is that it cannot be centrally monitored. Leaks are indicated by the flasher units that must be noted by an operator on a tank farm walk-through. The plus side of the compromise is that power and signal conduits to a central location are not required and overall installation and follow-on costs can be significantly less than other available technologies. The cable sensor system is simple in operation and provides good redundancy, since each sensor pipe and flasher unit is a stand-alone leak detection system.