COPING WITH UNDERGROUND GAS DURING CONSTRUCTION AND OPERATION OF THE LOS ANGELES RAIL SYSTEM

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INTRODUCTION

Underground gases of a combustible nature were not an unexpected problem in the implementation of the Los Angeles Metro Rail system. The presence of such gases throughout the Los Angeles Basin was known to the Metro Rail technical staff from the beginning of Preliminary Engineering. The question to be answered, however, was how to safely deal with this problem, both during construction and operations.

The original alignment of Metro Rail was established in 1981 based upon a First-Tier EIS and was selected as the Locally Preferred Alternative (LPA) in the Final EIS process completed in December 1983. As part of the engineering studies leading to the selection of the LPA, approximately 65 test borings were made along the route. Combustible gases were found in about 95% of these borings with pressures up to 194 in. W. C. and combustible percentages in air up to 95%. Hydrogen sulfide was also found in several of the test borings. The combustible gases, which are naturally occurring subsurface gases, were composed primarily of methane with some constituents of higher hydrocarbons.

The result of this investigation led to the conclusion that protective measures must be taken, both to prevent the intrusion of gases in the underground sections to the greatest degree feasible and to deal with the possible intrusion of gases should it occur. In addition, based on the test boring data, Cal-OSHA designated the entire underground length of the LPA as "GASSY", thereby requiring full compliance with Cal-OSHA's very stringent tunnel safety orders.

As luck would have it, or perhaps as an example of Murphy's Law, in early 1985, an explosion and fire occurred in the basement of a department store near the alignment of Metro Rail along Fairfax Avenue. This explosion resulted from methane gas migrating to the basement of the building leading to the explosion and fire.

This incident resulted in a Congressionally-ordered study to realign the central section of Metro Rail and not tunnel through the Wilshire-Fairfax area. This study has been completed and a new alignment has been adopted by the SCRTD Board. This alignment includes a significant amount of elevated section in the mid-corridor area. Additional borings were conducted along the route of the selected new alignment as well as along other candidate alignments and again, gases were found in most test wells. Use of an aerial configuration will mitigate the gas problem in the elevated sections of the new alignment.

The first segment of Metro Rail, which is currently under construction, is designated MOS-1 (Minimum Operable Segment - 1). It is approximately four miles long with five stations, all in subway. This initial segment was not affected by the realignment study and most major construction contracts have already been awarded. Planned initial revenue operations date is April 30, 1992.

The following sections of the paper address the specific measures to be taken by SCRTD to cope with underground gases - both during construction and after the system becomes operational. Two basic principles of safety have been followed. First, take steps to prevent a problem from occurring, i.e., prevent underground gases from penetrating into the Metro Rail tunnels and stations. Second, if intrusion does occur, provide safety apparatus and operating procedures that will deal with such intrusion before a major problem can occur.

CONSTRUCTION SAFETY MEASURES

Previous to the aforementioned underground gas explosion, SCRTD had already established vigorous safety precautions to be followed during the construction of Metro Rail. Cal-OSHA had classified the entire original route as "GASSY". This in turn imposed the Cal-OSHA California Administrative Code Title 8: "Industrial Relations," Chapter 4: "Division of Industrial Safety," Sub-chapter 20: "Tunnel Safety Orders", which is considered to be the best tunnel safety order in the country.

All Metro Rail contractors will be required to meet the following minimum underground safety construction requirements (summarized from the Tunnel Safety Orders):

a. Comply with Title 24, Part 3 (Electrical Regulations) and other special orders as may be issued by the Division of Industrial Safety (Division).

b. Smoking and other resources of ignition will be prohibited.

c. Welding, cutting and other spark-producing operations shall only be done in atmospheres containing less than 20 percent of the LEL (lower explosive limit) of methane and under the direct supervision of qualified persons.

d. Automatic and manual gas monitoring equipment shall be provided for the heading and return air of tunnels using mechanical excavators. The monitor shall shut down the equipment under specific defined conditions.

e. Air shall be tested for gas prior to entry after blasting (if used) and continuously when men are underground.

f. Records of gas tests and air flow measurements shall be available at the surface and to the Division.

g. Ventilation systems shall exhaust gas or vapors, shall have explosion relief mechanisms, and shall be fireproof.

h. Refuge chambers or alternate escape routes shall be provided and equipped with equipment acceptable to the Division. Workers shall be provided with emergency rescue equipment and trained in its use.

i. The main ventilation flow shall be reversible.

j. Fresh air shall be delivered in adequate quantities to all underground work areas. The supply shall be adequate to prevent hazardous or harmful accumulations of dust, fumes, vapors or gases, and shall not be less than 200 cubic feet per man per minute or a velocity of 60 feet per minute.

Additional construction safety measures have been adopted based upon two safety review boards convened after the underground gas explosion. The first board was an SCRTD in-house board of review and the second was an "Independent Technical Review Committee" established by the City of Los Angeles. These measures are:

1. Tunneling contractors will employ magnetometers to probe ahead of tunnel headings to locate abandoned oil or gas wells. In the event that any wells are found, procedures have been established in the contract specifications to safely plug and abandon them.

2. Special training will be carried out for all employees involved in underground construction. This training will cover both the operational requirements for work in tunneling in a "GASSY" environment as well as periodic emergency response training. These requirements are contained in the Metro Rail "Construction Safety and Security Manual," which has been reviewed and approved by Cal-OSHA and is a contractual requirement for all Metro Rail construction contractors.

3. Existing Metro Rail gas probes will be periodically monitored to see if any changes in gas measurements are taking place during construction. This could give advance notice of problems and allow appropriate precautions to be taken.

4. In the event that ventilation for underground construction does not provide adequate capability to dilute and remove gases, collection wells may be sunk ahead of the tunnel to disperse the gases to the atmosphere.

STRUCTURAL DESIGN AND CONSTRUCTION INTRUSION PREVENTIVE MEASURES

As previously stated, the first line of defense against underground gases after the system is constructed is to prevent the intrusion of these gases. Simply put - no intrusion, no problem.

In the first section of Metro Rail, MOS-1, the tunnel lining will be either precast reinforced concrete segments or cast-in-place reinforced concrete. The precast segments will be about 8 inches thick, covered on the outside surface with a hydrocarbon-resistant coating to resist the flow of gas through the concrete. All joints in the segments will have compressed gaskets and will be caulked to impede gas flow.

The cast-in-place liners will consist of steel ribs and wood lagging with a 12-inch cast-in-place final lining. A high-density polyethylene (HDPE) liner, about 100 mils thick, will be sandwiched between the initial and final linings.

Potential materials for the coating, lining and caulking underwent a detailed screening and testing program, beginning with a review of literature and of existing practices and applications. Over 30 products underwent this initial screening. Those materials passing the initial screening were subjected to tests for permeability, resistance to hydrocarbons and abrasion resistance. Two sources for the HDPE liner, three for the coating materials and three for the gasket materials have been selected and are called out in the construction specifications.

A further protective measure to be considered beyond MOS-1 is the use of a fabricated steel tunnel liner. This type of liner would give greater resistance to rupture from earthquakes which could cause a sudden influx of gases. Geological conditions encountered in future underground segments will be the determining factor for the type of tunnel liner to be employed.

OPERATIONAL PROTECTIVE MEASURES

The final protection against underground gases is the use of a gas monitoring subsystem to continuously provide early detection and annunciation of gas infiltration before a hazardous condition can develop. Annunciation of an increase in gas level above a normal ambient range will initiate gas control procedures and investigation of the source of the intrusion.

The gas monitoring subsystem consists of 12 central analyzers and 77 probes. Samples of air are extracted from tunnel and station exhaust and ventilation shafts and analyzed for methane and hydrogen sulfide content. The resolution of this equipment is such that it can detect concentrations of 1.0 part per million (ppm) or less of these gases. If abnormal concentrations of either gas are detected, the operators in the Rail Control Center (RCC) will be alerted. Normal operation of the analyzer equipment is completely automatic; however, provisions allow some equipment functions to be controlled remotely from the RCC.

The central-analyzer gas monitoring equipment consists of gas analysis instruments at a central location with sampling probes (tubes) extending from the instruments to the locations to be monitored. Air samples will be extracted from tunnels, ducts and shafts throughout the Metro Rail System for measurement of gas concentration levels. Air samples are drawn through sample probes to a vacuum pump; from the pump to a selector valve; from the valve to either the atmosphere or to the gas measurement instruments; then the sample leaving the instruments is exhausted to the atmosphere. Whether a sample is exhausted to the atmosphere immediately or goes to the measuring instruments prior to being exhausted is dependent upon the position of the sample stream selector valve. The selector valve switches the tube supplying the air sample to the measuring instruments after a preset time interval. In this manner, a sample from one tube at a time is routed to the gas measurement instruments. While one tube supplies the sample being analyzed, samples are continuously drawn through the remaining tubes. This sample stream switching operation continues in a cyclical manner, performing analyses of each sample once per cycle and allows each central analyzer to monitor the gas levels at multiple vent shaft locations. The continuous sample draw on all tubes ensures that a fresh sample, which is representative of current conditions, is delivered to the instruments.

Each analyzer can handle up to 8 probes. The sampling analysis time for both methane and hydrogen sulfide is specified to be two minutes or less for a complete analysis cycle for each analyzer of about 16 minutes.

Each central analyzer has two gas measuring instruments, one for methane and the other for hydrogen sulfide. Each gas measuring instrument within a central analyzer has two adjustable set points for annunciation of elevated gas levels. The first is called the warning set point, and the second, the alarm set point. The set point for the warning annunciation will be established during the construction phase, or shortly thereafter, because on-site ambient level gas measurements must first be determined for each segment. Data regarding ambient levels of methane and hydrogen sulfide will be evaluated as construction progresses. Once the normal range for a structure is determined, the warning set point can be established. For example, if ambient methane in a tunnel segment is found to have a normal range from 2 to 4 ppm while being ventilated, the warning set point might be established at 10 ppm to allow for fluctuations in ambient methane levels and ventilation system fluctuations.

A warning level annunciation will advise the RCC that an unusual influx of methane or hydrogen sulfide has occurred. Procedures for RCC reaction to annunciations will depend on location and levels. Plans include utilizing portable gas detection units to survey and locate the area/point of infiltration so that corrective measures can be taken. Also, supplemental ventilation may be provided to remove the gases from the tunnels or stations.

Alarm level set points will also depend on the ambient levels of gases in finished tunnel and station area. More consideration will be given to the effects of dilution, tunnel length, point-of-source concentration versus detected concentration, and other aspects before the alarm set point is established.

The performance of the central analyzer equipment is self-supervised and malfunctions will be annunciated at the RCC. Calibration of the measuring instruments is performed automatically on a daily basis to ensure accurate gas level readings and proper system operation.

Power for each central analyzer is 48 V dc from the Communications System. The power supply has a battery back-up floating on line so that analyzer supply voltage is not interrupted if there is a power failure in the main supply.

Each central analyzer has a microprocessor-based control unit to control functions, assure warning/alarm integrity, perform diagnostic checks, and communicate with the RCC through SCADA. The microprocessor allows control of central analyzer sequences from the RCC.

Each central analyzer automatically communicates the following information to the RCC:

- Methane measurement of each sample
- Hydrogen sulfide measurement of each sample
- Warning annunciation
- Alarm annunciation
- Trouble annunciation.

Each central analyzer will respond to RCC requests for:

- Selection of next sample to be analyzed
- Calibration of methane gas measuring equipment
- Calibration of hydrogen sulfide gas measuring equipment.

Equipment in the RCC will perform the following:

- o Record all gas measurements on a 24-hr active memory, presenting a 24-hour trend report

- o Record the highest gas measurement of each sample line, each day, on a 30-day memory

- o Record the 30-day memory data

- o Make a hard copy of all warning, alarm, and trouble annunciations

- o Provide a cathode-ray tube display of each warning/ alarm and trouble annunciation.

Procedures for RCC personnel to follow in the event of a warning, alarm or trouble annunciation are still being developed. The first two annunciations will probably involve use of the emergency ventilation system to supplement normal air flow in the affected underground sections, depending on the level of change indicated as well as the trend of increase in the change. Train operations may be stopped if conditions warrant. Maintenance personnel will be dispatched to the site of the gas intrusion as determined from the analyzer information. Hand-held gas detectors will be available for such investigations.

Three additional measures of protection against gas intrusion have been taken as a result of the Los Angeles City Independent Technical Review Committee (Committee).

First, the number of analyzers and probes was significantly increased. The Committee was concerned that sufficient probes were not planned and suggested that better diagnostic data for locating the source of gas intrusion should be obtained. Initially, gas probes were only located in exhaust ducts. This meant that gas intruding into the tunnel at any point would not be detected until it reached ventilation exhaust ducts. This did not allow for reasonably accurate location of the location of gas intrusions. The number of probes has been increased from 30 to 77 with 41 of the additional probes placed in the tunnel midway between stations. The number of central gas analyzers has been increased from 5 to 12, one of which is for the light rail portion of the 7th/Flower station.

The Emergency Gas Operating Procedures (EGOP) will call for activation of the emergency fans in the area where a warning or alarm originates. If the RCC controller has not taken such action within 30 seconds, the EGOP will be automatically initiated. The 30-second interval allows the controller to take other action if warranted by the operating conditions that prevail when the alarm is received. This automatic EGOP initiation was provided based upon a Committee recommendation.

The third measure is the addition of an emergency power backup supply for the ventilation system (and sump pumps) in the case of a major power loss to the system. Although an independent power feed had already been provided, the Committee was concerned that a major earthquake could cause loss of that backup as well as the basic supply. This loss of power could also rupture the tunnel, allowing a major gas intrusion. A standby generator will be installed in the Metro Rail yard, which can be switched to the existing backup power feed if the supply to that feed is lost. If an active earthquake fault is found during the construction of MOS-1, another such generator will be installed at the other end of the line, affording protection for the entire line.