Study of Methane and other Combustible Gases Effect On Underground Operation of the Metro Rail Project

Prepared by

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METHANE STUDY

1.0 INTRODUCTION

1.1 OBJECTIVE

The objective of the study is to determine whether or not a methane gas problem exists for the Metro Rail System, and, if such a problem exists, to determine its magnitude, and develop guidelines to avoid or mitigate the hazards of methane and other combustible gases in the underground Metro Rail System during revenue service.*

1.2 SCOPE

The scope of this work task is to analyze the existing available information, including geological data supplied by the District or their consultants, anticipated performance of structures, equipment and systems, and projected operation of the transit system as can reasonably be defined in this phase of design. This report is not intended to address the construction phase.

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* Analysis of gas samples collected and reported on in the "Geotechnical Investigation Report," Volume II, Appendix F-1 shows only a trace of hydrogen sulfide (H_2S). Further testing or experience may reveal higher percentages in the collected gas, and thus H_2S may be a future problem for the Metro Rail System.

This report presents the review of the information discussed in the previous paragraph and the study of the effect of methane and other combustible gases on the underground rail system.

1.3 INCORPORATION OF OTHER DATA AND REPORTS

The "Geotechnical Investigation Report" (GIR), prepared by the general geotechnical consultant, contains a significant amount of pertinent information and discussion of subsurface methane gas as it relates to a large segment of the proposed Metro Rail System route. The information contained in the GIR is of significant value to the reader of this report. Sections of the GIR which are of specific interest are reproduced herein, with permission; they are organized in a manner consistent with the structure of this report.

2.0 EXECUTIVE SUMMARY

The proposed Metro Rail System route will pass over or near six major oil fields. Over half the route is classified in the GIR as "potentially gassy" or "gassy" ground.

The potential for gas and related problems is supported by the experience of the Los Angeles City Fire Department, the California Division of Oil and Gas, and consulting engineers and construction contractors involved in excavation for construction projects located proximate to the route in segments classified as "gassy".

The presence of gas along the route may require special measures to preclude gas from entering the Metro Rail System. Methods exist, both passive and active, by which gas can be excluded from the Metro Rail System, if such measures are required.

The provision of a liner in the tunnel structure, which is a passive method, may not be feasible because of the need for joints and the resultant difficulty of preventing gas leaks at these joints and at the passenger stations. Gas collection and ventilation systems for managing and removing gas that intrudes into the tunnel during revenue operation is considered an active method. Ventilating and purging the tunnel interior of gas can be accomplished in varying degrees by different methods.

It is considered likely that, based on current information, gas will be a problem. Moreover, subsurface gas conditions could change over time, particularly following seismic activity. Thus, measures should be considered to accommodate such changes.

There are two possible approaches to consider in alleviating the potential gas problem: (1) proceed with design based on data available now and respond appropriately when and if more serious gas conditions are encountered during construction or, (2) conduct further investigations now with the expectation that the initial design, based on more comprehensive data, will preclude or greatly reduce special and costly conditions during construction.

Problems of in-service reliability, effectiveness, and cost are discussed for each method of control. Significantly, the use of a liner as a primary means of methane control has some potential major drawbacks and it seems prudent that it be studied further, at an early date so that its feasibility can be assessed.

In conclusion, the report recommends a series of steps for application during the design stages. One step which appears necessary in any case is the implementation of a gas detection system for use as either alarm and/or control.

3.0 DISCUSSION OF THE POTENTIAL METHANE GAS PROBLEM

3.1 COORDINATION WITH THE REFERENCED REPORT

At the inception of this task, the engineer was supplied a copy of "Geotechnical Investigation Report - Volumes I and II" (GIR) prepared by the general geotechnical consultant (Converse Ward Davis Dixon, Earth Sciences Associated and Geo/Resource Consultants) in November 1981. These extensive volumes contain considerable data and commentary relating to the presence of subsurface gas and oil in the general area of parts of the proposed route. Since the GIR will be extensively referenced and parts of it will be included in the present document, the same physical and geographical reference points and nomenclature employed in the GIR are used in this report.

3.1.1 Established Increments of the Proposed Route

The GIR, Subsection 5.1, Introduction, divides the proposed route into eight increments, called reaches.

> The proposed Metro Rail Project alignment is divided into eight reaches based on an assessment of the combined geologic, engineering, ground water, gas/oil and surface cultural features. It must be understood that the boundaries of each of the eight reaches are not sharp and must be considered transitional because they are based in part on interpretation of subsurface data and in part on surface features. These reaches [shown in this study in Figure 1] are as follows:
>
> Reach 1 - Downtown, Los Angeles River
>
> East Portal to the Hollywood Freeway (includes Borings CEG 1 through 6)
>
> Reach 2 - Broadway to Harbor Freeway
>
> Hollywood Freeway to Harbor Freeway (includes Borings CEG 7, 8 and 9)

Reach 3 - East Wilshire Boulevard

Harbor Freeway to Normandie Avenue (includes Borings CEG 10 through 14)

Reach 4 - Central Wilshire Boulevard

Normandie Avenue to La Brea Avenue (includes Borings CEG 15 through 18)

Reach 5 - La Brea Area

La Brea Avenue to Melrose Avenue (includes Borings CEG 19 through 23A)

Reach 6 - Hollywood Area

Melrose Avenue to Yucca Street (includes Borings CEG 24 through 28)

Reach 7 - Santa Monica Mountains

Yucca Street to Universal City Station (includes Borings CEG 28A through 34)

Reach 8 - San Fernando Valley

Universal City Station to the North Portal (includes Borings CEG 35 to 38)

3.1.2 Classification of Route Increments

The following, taken from the GIR, Volume I, Subsection 4.8, Project Tunnel Gas Classification, provides a classification, through an established and convenient system, of the probability of gas conditions in the areas of interest to the Metro Rail Project:

> Individual intervals of the alignment have been classified in terms of the relative likelihood of encountering gas, using the classification system contained in the Tunnel Safety Orders issued by the California Division of Industrial Safety. These classes, adopted from California Administrative Code, Title 8, p.684.18, are as follows:
>
> Nongassy - Applied to intervals where there is little likelihood of encountering gas during the construction of the tunnel.

Potentially gassy	- Applied to intervals where there is a possibility of encountering flammable gas or hydrocarbons.
Gassy	- Applied to intervals where it is likely gas will be encountered.
Extrahazardous	- Applied to intervals if the Division finds that there is a serious danger to the safety of employees.

Based on these criteria and data available at this time, [November 1, 1981] specific intervals of the proposed Metro Rail alignment have been classified. These specific intervals are shown [in this study on Figure 1] and listed below:

Borings CEG 1 to 4	- gassy [Reach 1 - eastern half is considered "potentially extrahazardous"]
Borings CEG 4 to 9	- potentially gassy [Reaches 1 and 2]
Borings CEG 9 to 12	- gassy [Reach 3]
Borings CEG 12 to 18	- potentially gassy [Reaches 3 and 4]
Borings CEG 19 to WC-8	- gassy [Reach 5 - entire reach considered "potentially extrahazardous"]
Borings CEG WC-8 to 38	- nongassy [Reaches 6, 7, and 8]

These preliminary classifications are considered approximate and are presented to alert the designer to the need to make provisions in the current engineering studies to cope with these areas. Actual conditions are expected to vary from those encountered in borings.

Although not shown...there is judged to be a potentially "extrahazardous" area along the proposed Metro Rail alignment in the eastern half of Reach 1 and the entire length of Reach 5.

3.2 EXPECTED BEHAVIOR OF GAS IN THE METRO RAIL SYSTEM AREA

Subsection 5.1.5.1, Gas, Section 5.0, Geologic Features of Engineering Significance, of the GIR, briefly discusses the expected behavior of gas and presents some observations of local conditions:

> Natural gases that formed at the depth related to known oil fields are likely to collect beneath perched water levels. Additionally, gases that collect beneath perched water levels are likely to migrate laterally. Consequently, gases may be present beneath the perched water levels in Metro Rail Project Reaches 3, 4, and 5 [Figure 1] even though these reaches are, in some cases, quite far from the known oil fields shown on Figure 1. Gases which migrate laterally are expected to collect in "pockets" at impermeable structural traps (often faults). The known faults that could be traps along the alignment are MacArthur, 6th Street, 3rd Street, San Vicente and Santa Monica faults.
>
> Determination of gas volume and pressure were beyond the scope of this study; however, the following observations were made:
>
> - Expansion of gas, in the sample tube, pushed the material 2 to 3 inches beyond each end of the tube during the drilling program in Boring CEG 1 (108 ft, Puente Formation claystone) and Boring CEG 23 (150 ft and 172 ft, siltstone interbeds in San Pedro Formation.
> - [*Omission*]
> - Gas was observed bubbling in Borings CDG 1, 2, 11, 19, 20 and 23.
> - Boring CEG 23 encountered the largest gas flow, and this fact is believed the result of gas being trapped by the Santa Monica fault; e.g., apparently gas could not migrate northerly into nongassy Reach 6. This fault may be comparable to MWD's San Fernando Tunnel at the Santa Susana faults where a fatal gas explosion occurred.
> - Tonner Tunnel was classified as "gassy" in the Puente Formation, but there was no problem because ventilation was adequate.

3.3 SUMMARY OF THE GEOTECHNICAL INVESTIGATION REPORT (GIR)

Finally, a "conclusion" reached in Volume I, Section 10.0, Specific Subsurface Problems in Design, of the GIR, sums up the general and potential magnitude of the problem as seen by its author.

> It is recognized that the proposed Metro Rail alignment will pass over or near six major oil fields (Section 4.7) [Figure 1] and over 50 percent of the alignment has been classified as either potentially gassy or gassy ground (Section 4.8 and Drawing 2). In addition to being a potential construction hazard, the presence of gas can reduce construction excavation rates substantially (Section 7.6), require special lining provisions for certain portions of the alignment (Section 7.7.5.2), <u>and mandate adequate collection and ventilation systems for the finished project</u> [emphasis added].
>
> We recommend the data, conclusions and cautions outlined throughout this report, particularly for Reaches 1 through 5, be implemented in regard to considerations for gas for current designs. If, however, more details than is presented in this report is required for design, it will be necessary to collect more field data. Such additional data might include locating and monitoring specific sources and pressures of gases at selected alignment locations.

The above excerpts from the GIR establish, with little doubt, the potential for problems associated with gas. Of considerable importance are indications that mitigation of the methane hazard during System operation may require active as well as passive measures of gas control, both of which will impact on the design, construction and operation of the Metro Rail System.

3.4 ADDITIONAL EVIDENCE OF THE EXTENT OF THE PROBLEM

3.4.1 California Division of Oil and Gas

A report on onshore oil and gas seeps was obtained from the California Division of Oil and Gas. A review of the data there-in revealed the existence of four "gas and oil" seeps with an assigned status of "active" as of June and July, 1971. These seeps are all in the area encompassing 6th and Fairfax, 6th and Curson, and Wilshire and Sierra Bonita. According to the report, activity in some seeps increased following the 1971 earthquake. The Division of Oil and Gas advises that no follow-up investigations or observations of these seeps have been conducted.

3.4.2 Los Angeles City Fire Department

In order to obtain an additional perspective, a meeting was held with Los Angeles City Fire Department personnel to determine whether the department's records would contain significant information on problems with gas. LAFD personnel present were Capt. William Lebeck, Inspectors James Pogue and Jon Hall, and Chief Wreesman of the Records Department. Unfortunately, the LAFD has had a modern fire record retrieval system for only about two years; thus, it would require extensive manpower and time to extract meaningful data from original fire reports. However, the Department has experienced, over the years, a continuing problem with gas seepage fires in the above-described areas. These fires are often started by a discarded cigarette from a passing pedestrian or motorist.

There have also been a number of fires at construction sites with excavations, many of these occurring from within a few miles to very close to the Wilshire/Fairfax area. Fire Department personnel described a recent construction project, adjacent to Wilshire Boulevard and the Metro Rail System route, and more than one mile from the La Brea Tar Pits, where excavation revealed a significant gas source. Subsequent boring and testing confirmed the presence of a gas pocket, 40 to 60 feet below grade, with an estimated volume of several million cubic feet. The measured static pressure was 110 oz/in^2 (about 7 lb/in^2) and the residual pressure, with an unknown flow rate, fell immediately to 70 oz/in^2 (about 4.5 lb/in^2) and later to 15.5 oz/in^2 (about 1 lb/in^2). After the flow was shut off, the static pressure recovered to 110 oz/in^2 in one hour. These data have been initially suggested by the Fire Department and confirmed by a highly qualified and experienced consulting engineering firm,* whose engineers are of the opinion that the pocket is interconnected with other pockets or strata of gas and that similar gas conditions may well be encountered elsewhere in the general area. These engineers also hold the opinion that gas conditions of this indicated severity require the active protection of subgrade structures, as well as passive protection within the structure itself.

4.0 DISCUSSION OF POSSIBLE SOLUTIONS

The effect of gas on Metro Rail operations can be mitigated by excluding gas from the System tunnel and/or managing gas that enters the tunnel.

4.1 EXCLUSION OF METHANE GAS FROM THE TUNNEL

4.1.1 Membrane or Liner

An impervious membrane or liner could be incorporated into the tunnel wall structure. An adequate test boring program, if initiated, should indicate with some degree of assurance, area(s) where a membrane or liner would and would not be required. However, the question of whether lateral migration of gas takes place over time, particularly during or after seismic activity, would need to be carefully addressed. If lateral migration does occur, the "spot" provision of membrane protection would not suffice, and a continuous membrane or liner would be mandated throughout those reaches where a potential exists for the presence of gas.

* Lockman & Associates, Consulting Engineers and Planners, 249 East Pomona Blvd., Monterey Park, CA 91754, (213) 724-0250. Dr. Ronald J. Lofy, PhD, PE, Vice President, is intimately familiar with the extensive work the firm has done for a number of clients in the solution of subsurface gas problems.

Another subject that must be addressed is the effect of seismic activity on the integrity of a membrane or liner. The proposed route crosses five faults (one is crossed twice) in areas classified as "gassy" and "potentially extrahazardous." One fault is in Reach 3 and the other four are in Reach 5. (The relationship between faults and gas is discussed in subsection 3.2.)

Liners have been used in underground transit, primarily to exclude water and other fluids (in some cases flammable). Approximate costs of $900/linear foot for ¼" steel liner can be expected.

4.1.2 Collection and Disposal of Methane Outside the Tunnel Structure

A method of subterranean gas collection, increasingly employed with naturally occurring methane as well as that produced in refuse landfill operations, uses underground, perforated piping, collection systems or "wells" from which gas is either naturally vented or pumped to the surface. After reaching the surface, the gas can be discharged to the atmosphere at an appropriate stack height above the surface, be flared off as with waste gas in refineries, or be collected and cleaned for on-the-spot use or for storage and delivery elsewhere. All of these methods are currently being employed by a variety of both public and private entities.

Examples of widely known implemetation have occurred in the marshlands of Northern New Jersey. In fact, use of collection systems is contemplated in the Wilshire area for problems encountered in building construction. These applications, however, tend to be site specific and not in linear configuration, possibly up to ten miles, as may be necessary here.

4.2 MANAGEMENT OF METHANE WITHIN THE TUNNEL

The four schemes of in-tunnel methane management presented below should not be viewed as separate alternates. They are versions of the same approach, differing only in the degree of reliability afforded, which will ultimately be dictated by the degree of exposure identified. These schemes can be employed in combination with passive measures.

4.2.1 Detection of Hazardous Gas/Air Mixtures

The flammable range of methane/air mixtures is generally accepted to be from 5% to 15% methane by volume in air at 70^{o}F and atmospheric pressure. Five-percent methane is the "lower explosive limit" (LEL) below which the mixture will not burn because there is insufficient fuel for combustion--the mixture is too "lean." Above 15% methane, the "upper explosive limit" (UEL), the mixture becomes too "rich" and will not burn because there is insufficient air for combustion.

In areas where flammable gas intrusion is a possibility, typical gas detection and alarm systems are set at selected fractions of the LEL; the LEL itself is never used as a practical limit. If an ultimate safety factor of 5, for example, is established, a "first alarm" at 20% of LEL might be selected and a "full emergency alarm" set at 40% of LEL.

4.2.2 Continual Purging of the Tunnel by Mechanical Ventilation

If it can be determined with reasonable certainty that gas intrusion will not exceed a certain rate, a ventilation system can be designed to ensure that the concentration of methane within the tunnel will remain below the appropriate level for both fire and health safety. However, for this method to be practical and acceptable as a sole source of control, the designers must be willing and able to guarantee that the actual intrusion rate would never exceed the design maximum.

4.2.3 Excess Methane Detection with Supplementary Purging

In order to provide increased safety and make the guarantee more acceptable, it might be practical to employ continuous purging (see 4.2.2 above) in conjunction with a methane detection and alarm system. This system should be arranged to detect an unacceptable increase in methane concentration and automatically actuate a higher-capacity purging fan system to effectively prevent an increased level of methane. It would be practical to provide such an emergency system on a zoned basis to minimize power consumption. Detection of excess gas would occur at one or two gas concentration levels which are adequately below the lower explosive limit of methane and air. The equipment would then transmit an alarm signal to alert operation and emergency personnel.

4.2.4 Excess Methane Detection with System Shutdown

In view of evidence set forth in Section 3.0 above, it seems entirely possible that ultimate safety still could not be reliably ensured even with incorporation of the method described in 4.2.3 above. As a final "worst case" emergency measure, two-stage methane detection and control could be employed. The first stage would be used to initiate supplementary purging over and above the continuous level. The second detection stage, which would activate at a higher level of methane concentration (but no higher than 40% LEL) would shut down System operation at the affected area or zone. Unless an acceptable upper limit of exposure to gas intrusion can be established, the possibility of some extreme emergency condition developing must be acknowledged and provided for within sound limits of cost effectiveness.

4.3 DISCUSSION OF POSSIBLE PROBLEMS

4.3.1 Reliability of Ventilation Equipment

The reliability of the fan units and their power supply is important because, for this use, they become emergency fire/ life safety equipment and must have commensurate reliability built into them. No matter how high the level of reliability desired for a system, the actual level can never reach 100%. Any ventilation system will at some time unexpectedly fail and at other times will need to be shut down for maintenance. Thus, the role of an extensive ventilation system consisting of fans, power sources, and control devices for continual or supplemental purging has inherent limitations.

4.3.2 Explosion-Proof Electrical Equipment

The unlikely, but possible, condition where the concentration of gas in the tunnel rises to a dangerous level at the same time that the ventilation or purge system is shut down introduces the need for expensive explosion-proof electrical components. Such equipment would be necessary for this condition since it would be mandatory to start up the ventilation system at a time when there is an abnormal gas concentration in the tunnel. The possibility cannot be ignored that pockets of gas concentration, close to or above the LEL, might exist near electrical switches, motors, or other components which represent an ignition source. Some level of explosion-proof electrical equipment providing critical functions must be adopted as design requirements, regardless of the gas control method selected.

4.3.3 Gas Detection and Alarm Equipment

If mechanical ventilation is to be employed for control of gas within the System structures and its operation is to be initiated by the presence of gas, then facilities for automatic detection of gas must be provided.

Gas detection systems have been in use for many years in mines, chemical plants, and the like. The state-of-the-art equipment is fairly sophisticated. The need for such systems is usually in a limited area and involves a relatively small number of detectors. To provide an acceptable level of reliability for the Metro Rail System, it may need redundant detectors, extensive control system, reliable power supply (probably batteries), and interface with Metro Rail System alarm and ventilation systems. The detectors may also be required to be suitable for electrical hazardous locations.

The limited use of this type of system in transit systems has proven to be a problem. Frequent maintenance, calibration, and replacement due to environmental conditions (sumps, etc.) are generally required. Thus, maintenance costs would be a major factor in the annual cost.

5.0 CONCLUSIONS

5.1 GEOTECHNICAL INVESTIGATION REPORT

Section F1.5, Conclusions, in Volume II of the GIR, which is quoted below, offers a succinct and appropriate partial conclusion to this study.

> Based on available data and known geology, the subsurface conditions for purposes of tunnel classification must be considered as "extrahazardous": (20% lower explosive limit) along the alignment in the area of known oil fields.
>
> In areas between the oil fields, we may expect to find gas in the subsurface. These areas may be classified as gassy (5% lower explosive limit) and/or potentially gassy.
>
> Because of the possible lateral migration of gases below the zones of perched water, it is likely that gases have accumulated under pressure in the stratigraphic and structural traps (e.g., faults of igneous dikes along the southern part of the Santa Monica Mountains) at distances away from the

immediate areas of known oil fields. Such areas would be approached cautiously with appropriate testing of gases during the driving of the tunnel. In addition, extreme caution should be exercised whenever the driving of the tunnel approaches the area below a perched water zone, and appropriate gas testing should be done.

5.1.1 Expectation

Based on the data and information available at this time and, more specifically, on the fact that a troublesome pocket of gas has recently been encountered by others within a few hundred feet of the proposed System alignment,* it is considered likely that gas will ultimately prove to be a problem for the Metro Rail System.

5.1.2 Accommodation of Future Subsurface Changes

It is reasonable to expect some changes in subsurface conditions with the passage of time. Concentrations of gas below the surface are not considered necessarily static. They can change location over time, particularly when their presence and location are dependent on faults and associated seismic activity. Thus, it is possible that measures taken to mitigate the methane problem (based on early subsurface analysis) may be rendered ineffective through seismic activity at some future time, unless such measures are designed to accommodate changes in subsurface conditions with respect to gas.

5.2 DIRECTIONS FOR THE IMMEDIATE FUTURE

There are several basic alternative approaches (5.2.1 and 5.2.2) which can be taken at the present time. However certain tasks, included in the rest of the following, appear to be prudent in any event.

* See Subsection 3.4.2 and footnote.

5.2.1 Utilize Construction Phase for Investigation

This alternative entails proceeding with the design of the Metro Rail System using known data concerning gas as a basis for the selection and design of measures by which gas will be excluded from or managed within the System. Effectively dealing with unanticipated severe gas conditions, if and as encountered during construction, would be a problem and must be considered with this alternative.

5.2.2 Initiate Further Subsurface Investigation

Additional testing and subsurface investigation, at shorter intervals along selected segments of the proposed Metro Rail alignment, to further identify and define the probable extent and magnitude of the ultimate gas problem is considered to be worthwhile. The results should permit selection and design of mitigation measures with a much greater degree of confidence. The discovery of unanticipated severe gas conditions during construction will be eliminated, at best, or significantly reduced, at worst.

The trade-off with this alternative is the cost of additional subsurface investigation at an early stage versus the aggregate cost of having construction unexpectedly halted, solving the immediate construction site problems of escaping gas, possible death or injury to personnel and/or property damage or loss of equipment if a fire should occur, and the cost of redesign and the probable significant delay in construction.

5.2.3 Study Effectiveness of Liner or Membrane

The use of a tunnel liner or membrane is an attractive full or partial solution to the overall gas problem because it is a passive method and does not incur any operation or maintenance costs. It would be prudent to study the viability of this method at an early date.

This method does have some major drawbacks and limitations. A liner probably will have to have joints at intervals, if for no other reason than to allow for expansion. Joints or total interruptions at both ends of passenger stations will be required since it does not seem practical to construct a complete liner enclosing a station structure.

The use of metal liners also leads to an increased susceptibility to the effects of fire. Depending on actual design, use of joints, expansion requirements, bonding and other factors, temperature tolerance is less than reinforced concrete. Although agreement as to exact temperature threshold is still debatable on existing facilities, a temperature set point indicating failure below 1000° F is to be expected.

If there are joints, there will almost certainly be leaks. For the resultant leaks, gas detection and tunnel ventilation will be required. These measures are, in fact, the alternates to the use of a liner in the first place.

5.2.4 Gas Detection

Gas detection appears to be required in any combination of solutions. From this view point, design should include incorporation of combustible gas detection in any section of the tunnel or a station where gas intrusion is proven or possible (Reaches 1 through 5).

5.2.5 Ventilation

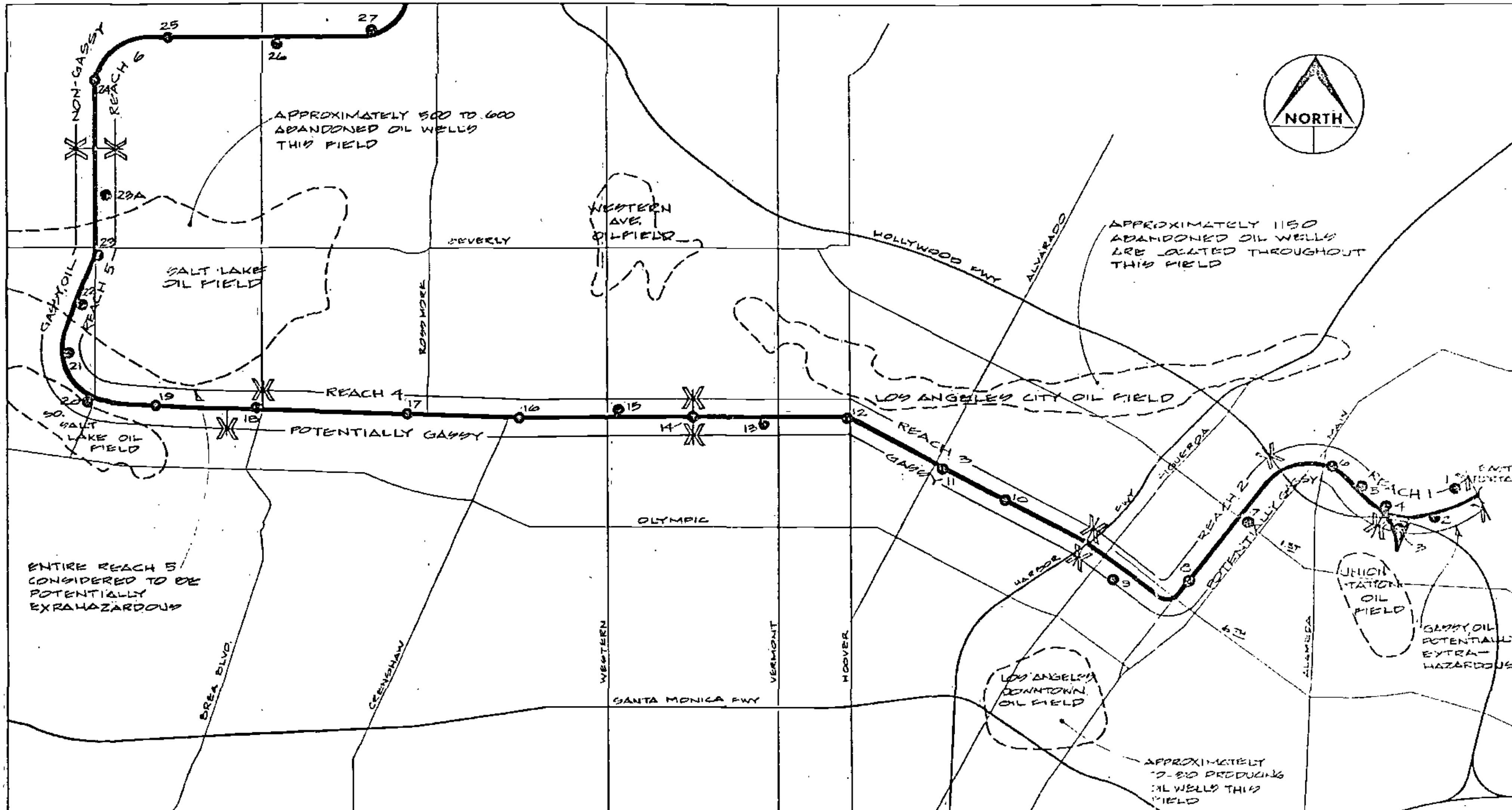
Ventilation will be provided in any case for other purposes and prudent steps to utilize these systems for methane management should be taken. Use of ventilation could be continuous, intermittent, or only as needed. Controls for ventilation and possible interface with gas detection should be anticipated and the designs incorporate, or at least require, minimal modification to utilize ventilation for gas accumulation management. The designs should also consider and provide for prevention of stratification or pockets in the facilities/ventilation relationship.

5.2.6 Gas Collection

Collection of gas external to the tunnels and stations is the least understood of the alternatives. A further examination of the capabilities and limitations of this technique should be done. Since the liner (membrane) solution would be most difficult for the stations, utilization of collection systems may be necessary.

5.2.7 Ventilation System Design

The ventilation system will be designed to exhaust the gas from the tunnels to the outside atmosphere. The potential constraints to this approach with regard to appropriate environmental regulations is beyond the scope of this report and needs to be examined.



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CALIFORNIA DIVISION OF OIL & GAS
ONSHORE OIL & GAS SEEPS IN CALIFORNIA, 1980-81

SOUTHERN CALIFORNIA RAPID TRANSIT DISTRICT

METRO RAIL PROJECT

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CHECKED BY: VIED
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