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Diesel Emissions and Ventilation Exhaust Sampling in the North Ramp of the Yucca Mountain Project Exploratory Studies Facility

J. T. George

Prepared by
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Albuquerque, New Mexico 87185 and Livermore, California 94550
for the United States Department of Energy
under Contract DE-AC04-94AL85000

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Diesel Emissions and Ventilation Exhaust Sampling in the North Ramp of the Yucca Mountain Project Exploratory Studies Facility

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ABSTRACT

A series of ventilation experiments have been performed to assess the potential retention of diesel exhaust constituents in the North Ramp of the Yucca Mountain Site Characterization Project's Exploratory Studies Facility (ESF). Measurements were taken to help evaluate the potential impact of retained diesel exhaust constituents on future in-situ experiments and long-term waste isolation. Assessment of the diesel exhaust retention in the ESF North Ramp required the measurement of air velocities, meteorological measurements, quantification of exhaust constituents within the ventilation air stream, multiple gas sample collections, and on-line diesel exhaust measurements. In order to assess variability within specific measurements, the experiment was divided into three separate sampling events. Although somewhat variable from event to event, collected data appear to support pre-test assumptions of high retention rates for exhaust constituents within the tunnel. The results also show that complete air exchange in the ESF does not occur within the estimated 16 to 20 minutes derived from the ventilation flowrate measurements. Because the scope of work for these activities covered only measurement and acquisition of data, no judgment is offered by the author as to the implications of this work. Final analyses and decisions based upon the entire compendium of data associated with this investigation is being undertaken by the Repository and ESF Ventilation Design Groups of the Yucca Mountain Site Characterization Project.

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1.0 INTRODUCTION

The Yucca Mountain Site Characterization Project (YMP) is currently assessing the feasibility of locating a high-level nuclear waste repository¹ at Yucca Mountain, Nevada. Final determination of the suitability of the proposed site to contain and isolate nuclear waste will depend on the results of surface-based and in-situ characterization activities. The focus of the in-situ characterization program is a series of experiments planned for the Exploratory Studies Facility (ESF).

Construction of a ramp access to the ESF facility has been initiated using a tunnel boring machine (TBM). The ESF ramp design specifies a nominal decline of two to three percent. Because of this decline, the carrying capacity of the battery powered trains used for muck removal becomes limited as the TBM advances downward. As the muck removal capacity decreases, the advance rate of the TBM also decreases. A continuous electric conveyor system was proposed in the original designs for the ramp; however, the economic advantage of using surplus diesel locomotives in the excavation and operation of the north ramp of the ESF prompted an evaluation of the technical implication of diesel haulage (TRW, 1994).

The primary regulation against which an evaluation of diesel haulage must be judged can be found in Title 10, Part 60 of the Code of Federal Regulations (CFR)(NRC, 1986). Specifically, 10 CFR 60.15(c)(1) states that investigations at the proposed site *shall be conducted in such a manner as to limit adverse effects on the long-term performance of the geologic repository to the extent practical* (NRC, 1986). Emissions from diesel powered equipment may represent a significant source of foreign compounds that could be detrimental not only to the planned ESF studies, but also to long-term waste isolation.

Diesel emissions typically contain unburned hydrocarbons, as well as nitrogen, sulfur, and oxygen compounds. In the evaluation of diesel haulage (TRW, 1994), the only outstanding issue related to diesel emissions was the calculated concentration of the oxides of nitrogen (NO_x).

¹ The term *repository* appears throughout this document. The use of the term *repository* to identify the facility or some portion of the facility that may be constructed and operated at Yucca Mountain is not intended to imply that such a facility will be constructed or operated at this site.

The calculated NO_x concentrations exceeded limits established in draft guidelines for the ESF north ramp (TRW, 1994). The calculations were based on several highly conservative assumptions, including a 100% retention of NO_x compounds within the tunnel. Recognizing that this 100% retention assumption may be overly conservative, a recommendation was made by the management and operation (M&O) contractor of the YMP to perform a test of the ventilation exhaust airstream when a diesel locomotive was in operation in the ramp. The conduct of such an experiment is consistent with the air quality and ventilation investigations outlined in the In Situ Design Verification Study defined in Section 8.3.1.15.1.8 of the Site Characterization Plan (SCP) (DOE, 1988).

This report summarizes activities initiated to measure the components of diesel exhaust associated with the normal operation of diesel equipment in the North Ramp of the ESF. Activities defined as part of the experiment included taking undiluted emissions samples from the diesel locomotive, diluted samples from the ventilation ductwork and tunnel, velocity traverse measurements within the tunnel and ventilation exhaust line, as well as standard meteorological measurements (e.g., temperature, barometric pressure, and relative humidity). Presented first is a description of the facility (as tested) and the instrumentation used to gather data. This is followed by a presentation of the experimental procedure and a discussion of selected data. Finally, results are discussed and recommendations for improvement presented. A complete set of data is included in Appendices A through D.

2.0 EXPERIMENTAL LAYOUT

At the time of the experiment (April 29, 1995), the advance of the north ramp was 633.86 m (Figure 2-1). The first 61 m (200 ft) of the starter tunnel is 9.4 m (31 ft) high and 9.1 m (30 ft) wide with an arched roof. Beyond 61 m, the mined cross section of the ramp is circular with a nominal diameter of 7.6 m (25 ft) (Figure 2-2). Due to the installation of concrete invert segments, the ventilated cross section beyond 61m is not circular. The exhaust ventilation system at the ESF consists of a nominal 1.68-m (66-in) diameter duct extending from an area just behind the TBM to a point approximately 10 m (32 ft) inside the tunnel portal. Connected to this 1.68-m diameter duct is a 1.06-m (42-in) diameter duct that links the main exhaust ventilation line to a 2.13-m (84-in) tall external stack.

Acting as the source of diesel emissions for the experiment was a 13.6 metric ton locomotive powered by a Deutz F8L413FW diesel engine. The locomotive was positioned 76.8 m (252 ft) inside the north ramp portal, providing for the maximum possible retention of any diesel emissions prior to entrainment in the ventilation exhaust system.

2.1 Instrumentation

For this experiment, concentrated diesel emissions were monitored at the locomotive exhaust and dilute diesel emissions were monitored at the location shown in Figure 2-3. Grab samples using Summa® canisters were also taken at the locations shown in Figures 2-3, 2-4, and 2-5 to establish the concentrations of volatile organic compounds (VOC) within the tunnel and its ventilation system. In addition, background data on the velocity fields within the tunnel and the ventilation ductwork were taken along with meteorological information. Presented below are discussions of the instrumentation used to obtain the experimental data along with pertinent equipment specifications.

2.1.1 Concentrated Diesel Exhaust Constituents

The measurement of undiluted diesel exhaust constituents was accomplished using an ENERAC™ 3000 Compliance Level Analyzer configured to aspirate exhaust

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Figure 2-1. Major ESF accesses showing diesel emission test locations.

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Figure 2-2. Cross sectional view of (a) starter tunnel and (b) north ramp.

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Figure 2-3. Plan, elevation, and front views of the diesel emission testing locations in the ESF north ramp.

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Figure 2-4. Underground VOC sample canister locations.

Not to Scale

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Figure 2-5. Schematic of gas constituent sampling manifold.

samples directly from one of the two locomotive exhaust ports. ENERAC™ equipment has historically been used at the NTS for the determination of emissions hazards to human health; therefore, its use for the measurement of undiluted diesel exhaust constituents was suggested by the site contractor (REECo). The ENERAC™ 3000 employs electrochemical sensor technology to determine levels of nitric oxide (NO), nitrogen dioxide (NO₂), carbon monoxide (CO), and sulfur dioxide (SO₂). From these measurements, the ENERAC™ 3000 calculates the levels of carbon dioxide (CO₂) and the oxides of nitrogen (NO_x). The ranges, resolution, and accuracy for the measured and calculated values reported by the ENERAC™ 3000 are presented in Tables 2-1 and 2-2.

Table 2-1. Range, Resolution, and Accuracy of ENERAC™ 3000 Measured Parameters

Measured Parameters	Range	Resolution	Accuracy
Nitric Oxide (NO)	0 - 1,000 ppm	1 ppm	2 % of Reading
Nitrogen Dioxide (NO ₂)	0 - 500 ppm	1 ppm	2 % of Reading
Carbon Monoxide (CO)	0 - 2,000 ppm	1 ppm	2 % of Reading
Sulfur Dioxide (SO ₂)	0 - 2,000 ppm	1 ppm	2 % of Reading

Table 2-2. Range, Resolution, and Accuracy of ENERAC™ 3000 Calculated Parameters

Computed Parameters	Range	Resolution	Accuracy
Carbon Dioxide (CO ₂)	0 - 40 %	0.1 %	5 % of Reading
Oxides of Nitrogen (NO _x)	0 - 1,500 ppm	1 ppm	2 % of Reading

The manufacturer claims that the ENERAC™ 3000 will meet requirements set forth in 40 CFR 60 Appendix A, Method 6C5.1.5 (EPA, 1994a) and Method 7E.5 (EPA, 1994b). However, no documentation of compliance to National Institute of Standards and Technology (NIST) or other nationally recognized standards could be established for the analyzer. A vendor-supplied calibration² certificate indicating that the instrument has

² The term *calibration(s)* appears throughout this document. The use of the term *calibration(s)* does not necessarily imply concurrence with SNL Quality Implementing Procedure 12-1. Usage of the term *calibration(s)* in this document denotes field checks performed on instrumentation using vendor procedures and vendor certified gases.

a "certified 2% accuracy" was furnished with the unit. In addition, span gases³ were used to check the algebraic difference between the upper and lower range values during the manufacturer-recommended field check. Gases used were supplied by the manufacturer; however, no documentation of compliance with NIST or other nationally recognized standards has been established for the gases.

The manufacturer specified that the ENERAC™ 3000 should be subjected to a complete span calibration once every four months. Using a vendor-supplied calibration kit, a successful calibration per the manufacturer's requirements was completed 72 hours prior to the use of the instrument in the ESF. In addition, the manufacturer recommended practice of auto zeroing the instrument at the beginning of the day of measurements was followed.

2.1.2 Dilute Diesel Exhaust Constituents

Sampling of the dilute diesel constituents carried in the ventilation exhaust line was accomplished by positioning a 19-mm (0.75-in.) stainless steel sampling probe at the geometric center of the 1.68-m diameter ductwork. The sampling probe, fabricated with a 90° elbow and extension tube, opened directly into the oncoming airflow carrying the diluted exhaust constituents (Figure 2-3). The probe was installed approximately 6.7 m (22 ft) upstream of the ventilation system's transition to the 1.06-m (42-in.) diameter duct that connects the system to the external stack. Approximately 30.5 m (100 ft) of 19-mm (0.75-in.) diameter Teflon tubing was used to connect the probe to a sampling manifold located in a portable trailer positioned just outside the tunnel portal (Figure 2-3 and 2-5). Air was aspirated from the ventilation exhaust line by a connection to the suction side of the sample manifold pump (Figure 2-5). Excess air was bled off using a bleed adapter mounted upstream of the fan to prevent overpressure conditions in the manifold.

Measurements of the diluted diesel exhaust constituents were made using EPA approved analyzers manufactured by Thermo Electron Corporation (TECO), specifically, models 42, 48, and 43A. The TECO analyzers use chemiluminescence for the detection of NO, NO₂, and NO_x; gas-filter correlation for the detection of CO; and pulsed-

³ Compressed gas formulated to contain quantified concentrations of constituents, but not exceeding the maximum range of the constituents being measured.

fluorescence for detection of SO₂. In addition, a NOVA Corporation Model 421P monitor employing infrared technology was used for the detection and measurement of CO₂. Table 2-3 presents the range, resolution, and accuracy for the TECO and NOVA instruments used to quantify the dilute diesel exhaust constituents.

The TECO analyzers were factory calibrated to meet EPA standards for the measurement of the constituent gases listed in Table 2-3 (with the exception of carbon dioxide) pursuant with the requirements defined in Title 40, Part 53 of the Code of Federal Regulations (EPA, 1993). In addition, onsite calibrations of the TECO and NOVA instruments were also accomplished. Instrument output was validated by performing pre- and post-test measurement calibrations. During the pre-test calibration, precise concentrations of certified span gas mixtures were introduced into the instruments per manufacturer's specifications. The certified span gas mixtures were produced using cylinders of known concentration gases, and *zero air*⁴ to achieve desired concentrations.

With the exception of the NOVA CO₂ monitor, instruments were then checked at four separate points: 80%, 50%, 20% , and 0% of full scale. The NOVA CO₂ monitor was zeroed and given a one point span check at 50% of full scale using a certified span gas. Post-test checks of the instrumentation consisted of span checks (i.e., checking the algebraic difference of the upper and lower bounds for a particular range) using certified span gases.

Table 2-3. Range, Resolution, and Accuracy of TECO and NOVA Instruments

Parameter	Range	Resolution	Accuracy
Nitric Oxide (NO)	0 - 1 ppm	.50 ppb	+/- 1 % Full Scale
Nitrogen Dioxide (NO ₂)	0 - 1 ppm	.50 ppb	+/- 1 % Full Scale
NO _x (NO +NO ₂)	0 - 1 ppm	.50 ppb	+/- 1 % Full Scale
Carbon Monoxide (CO)	0 - 1 ppm	.10 ppm	+/- 1 % Full Scale
Sulfur Dioxide (SO ₂)	0 - 1 ppm	.60 ppb	+/- 1 % Full Scale
Carbon Dioxide (CO ₂)	0 - 2,000 ppm	.10 ppm	+/- 2 % Full Scale

⁴ Compressed gas formulated to contain zero concentrations of constituent being measured.

2.1.3 Volatile Organic Compounds

Passivated Summa® sampling canisters with 15 liter capacities were used to obtain ventilation air samples during the experiment at three locations: upstream of the locomotive 16.8 m (55 ft) inside the portal, downstream of the locomotive 151.9 m (498.3 ft) inside the portal, and from within the ventilation ductwork (Figures 2-5). Samples from within the tunnel were taken only once during the experiment, and were obtained at the centerline of the drift at height of 1.5 m (5 ft) above the invert. Ventilation ductwork samples were drawn via the diluted diesel exhaust constituent sampling probe discussed in section 2.1.2., and were obtained during each of the three sampling periods.

Analyses of the VOC samples were performed in accordance with the EPA Compendium Method (for) Toxic Organics (T.O.)-14 (EPA, 1988). No calibration standards exist for the Summa® canisters used to obtain grab samples; however, procedures were followed in cleaning and passivating canisters prior to sample collection as specified in the EPA Compendium Method TO-12 Determination of Non-Methane Organic Compounds (NMOC) in Ambient Air Using Cryogenic Pre-Concentration and Direct Flame Ionization Detection (PDFID) (EPA, 1988).

2.1.4 Velocity Traverse Measurements

Ventilation in the ESF is such that fresh air is drawn through the portal opening, traversing the entire length of the tunnel until such time as it is picked up by the ventilation system in an area near the face of the tunnel. It is within these airstreams that velocity and meteorological parameter samplings were performed.

Traverses within the tunnel were made at locations 16.8 m (55 ft) and at 151.9 m (498.3 ft) inside the portal, corresponding to VOC sampling locations (Figures 2-3 and 2-5), using a hand held Davis DA-4000 anemometer at points along the approximate horizontal and vertical axes shown in Figure 2-6. The ventilation ductwork traverses required the use of two ports 90° from each other positioned approximately 16.8 m (55 ft) from the portal. Traverses made within the ductwork were done in accordance with 40 CFR 60 Appendix A Method 1 (EPA, 1994c). Measurements were made using a

Starter Tunnel Survey (16.8 m from portal)	
Vertical (m) (floor to top)	Horizontal (m) (left to right)
0.4	0.4
1.4	1.4
2.9	2.9
4.9	4.9
6.9	6.9
_____	8.2
_____	9.3

Tunnel Bore Survey (151.9 m from portal)	
Vertical (m) (floor to top)	Horizontal (m) (left to right)
0.3	0.4
0.8	1.1
1.7	2.2
2.9	3.6
4.3	5.0
4.9	6.1
5.5	6.8

Ventilation System Survey (16.8 m from portal)	
Vertical (m) (top to floor)	Horizontal (m) (right to left)
0.2	0.2
0.3	0.3
0.5	0.5
0.8	0.8
1.2	1.2
1.4	1.4
1.5	1.5

Vent Line

Note: All sections viewed looking into tunnel from the portal

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Figure 2-6. Velocity traverse measurement cross-section locations.

standard 1.5-m (60-in) pitot tube and an electronic manometer. The specifications of the equipment used to make velocity traverse measurements are presented in Table 2-4.

Table 2-4. Specifications for Velocity Measurement Instrumentation

Instrument	Range	Accuracy
Davis DA-4000 Anemometer	0.35 to 40 m/s	±1%
Dwyer 400-10 Pitot Tube	400 to 12,600 ft/min (2.03 to 64.0 m/s)	±0.25%
Dwyer 475-2 Manometer	0 to 40 in (H ₂ O) (0 to 9963 Pa)	±0.50%

2.1.5 Meteorological Measurements

Meteorological parameter sampling was performed in conjunction with the velocity traverse measurements made within the tunnel and ventilation ductwork. Barometric pressure readings were taken immediately adjacent to the instrumentation trailer (Figure 2-3). Relative humidity and temperature measurements were conducted at points within the tunnel at locations 16.8 m (55 ft) and at 151.9 m (498.3 ft) inside the portal.

Table 2-5 provides a list of the instrumentation used to gather meteorological data during the experiment and their associated ranges and accuracies.

Table 2-5. Instrumentation Used to Gather Meteorological Information

Parameter/Instrument	Range	Accuracy
Temperature: Vaisala HMI-31	-40 to 40 C	±0.3C
Relative Humidity: Vaisala HMI-31	0 to 100%	±3%
Barometric Pressure: A.I.R. AIR-B-1A	600 to 1000 mb	±0.3 mb

2.2 Conduct Of Experiment

All activities covered by this report took place over a seventy-two hour period from April 26, 1995 to April 29, 1995. Calibration and pre-test checks of the ENERAC™

3000 were conducted April 26, 1995. All pre-test field calibrations of the TECO and NOVA instrumentation, pre-test velocity traverses and meteorological measurements were conducted April 28, 1995. These activities were conducted twenty-four hours in advance in order to devote the maximum amount of time to the ventilation exhaust sampling activities during the test. Operational history as well as vendor-supplied information indicated that the instrumentation would remain stable for several days once calibrated and powered up. Ventilation exhaust measurements and VOC sample collection were carried out on April 29, 1995 in three one-hour stages.

Prior to the start of data collection, appropriate field checks of all instrumentation were completed. A vacuum of 3.0 in of water was established on the sample line connected to the ventilation ductwork. Ambient air analysis was then performed using the TECO and NOVA instruments connected to the sample manifold.

2.2.1 Stage 1

The diesel locomotive was pre-warmed for two hours, approximately 200 m from the portal, to allow the catalytic converter to achieve optimal operating temperature. Once the locomotive had been warmed up, it was moved into position 76.8 m (252 ft) into the tunnel (Figure 2-3). Following a 20 minute period of idling within the tunnel, the locomotive was set at the chosen test speed of 2300 rpm. Twelve minutes after test speed had been established, the valve on the downstream passivated Summa® canister (Figure 2-5) was opened; this was considered a sufficient time interval to allow for the exhaust mixture within the tunnel to stabilize. The valve remained open on the downstream canister for 23 minutes. The valve on the portal Summa® canister (Figures 2-3 and 2-5) was opened 14 minutes after test speed was established, and was allowed to sample for 57 minutes. The VOC sample collection from the ventilation system (via the sample manifold) (Figure 2-4), was not initiated until the locomotive had been at test speed for 25 minutes, which is consistent with the estimated time needed to achieve a complete air change within the tunnel. VOC sampling from the sample manifold for Stage 1 of the experiment continued for 60 minutes.

The locomotive remained in the tunnel for 72 minutes, during which time the ENERAC™ 3000 and the TECO and NOVA analyzers quantified the undiluted diesel exhaust at 1-minute intervals and diluted diesel exhaust constituents at 5-minute intervals.

A 25 minute period was allowed between the removal of the locomotive from the tunnel and the start of Stage 2 of the experiment. It was believed that this provided sufficient time for the air within the tunnel to be completely exchanged based on velocity traverse data. Ventilation line sampling continued during this period to provide substantiating information for the velocity traverse data, by monitoring the rampdown of exhaust constituent values. The continued sampling period also established initial conditions for the next stage of the experiment.

2.2.2 Stage 2

The locomotive was returned to its designated position in the tunnel and allowed to idle for 7 minutes prior to the establishment of the 2300 rpm test speed. Twenty-three minutes after the locomotive had been positioned in the tunnel, VOC sample collection was initiated from the sample manifold connected to the ventilation exhaust line. The VOC sampling from the sample manifold was maintained for 41 minutes.

For Stage 2, the locomotive stayed in the tunnel for 66 minutes, during which time the ENERAC™ 3000 and the TECO and NOVA analyzers quantified the undiluted diesel exhaust at 1-minute intervals and diluted diesel exhaust constituents at 5-minute intervals. A 31 minute period was allowed between the removal of the locomotive from the tunnel and the start of Stage 3 of the experiment. Dilute constituent measurements were continued during this period to provide substantiating information of the velocity traverse data, as well as initial conditions for the next stage of the experiment.

2.2.3 Stage 3

The locomotive was returned to its designated position in the tunnel and the test speed of 2300 rpm reestablished. Twenty-six minutes after the locomotive had been positioned in the tunnel, VOC sample collection was initiated from the sample manifold connected to the ventilation exhaust line. VOC sampling from the sample manifold was maintained for 32 minutes.

For Stage 3, the locomotive stayed in the tunnel for 64 minutes, during which time the ENERAC™ 3000 and the TECO and NOVA analyzers quantified the undiluted diesel exhaust at 1-minute intervals and diluted diesel exhaust constituents at 5-minute intervals. Sampling of the ventilation exhaust airstream was not continued after the locomotive exited the tunnel because of flow rate problems within the sampling manifold.

2.2.4 Post-Test Instrument Calibration

As discussed in Section 2.1.2, span checks on the TECO and NOVA instruments using *zero air* to achieve an instrument measurement parameter of zero, followed by the subsequent introduction of certified span gases to achieve a specified instrument reading between 0 and 100% full scale (depending on the instrument and span gas used), were successfully performed. No further checks or calibration of the ENERAC™ 3000 were performed.

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3.0 DATA AND OBSERVATIONS

The complete sets of data for the April 29, 1995 experiment can be found in Appendix A. Selected data are presented in this chapter for comparison to manufacturer specifications for the tested engine, as well as data related to the retention of NO_x within the tunnel.

3.1 Comparison To Manufacturer's Specifications

The engine manufacturer provided emissions specifications for a wide range of speeds and loads (TRW, 1994). Table 3-1 presents the manufacturer's emissions specifications for NO_x, CO, and CO₂ based on an engine speed of 2300 rpm and zero load. Examination of the concentrated diesel exhaust data indicates that the measured maximum average values for all engine exhaust constituents fell well below the manufacturer's specifications. It is worth noting that the differences between manufacturer specifications and data may be due to a number of factors including ongoing preventive maintenance programs, use of low sulfur fuels, and changes in engine injection timing. Table 3-1 should not therefore be taken as sufficient justification for the use of diesel equipment in the ESF. Note that levels of SO₂ are not reported in Table 3-1; SO₂ was not considered a critical parameter since low sulfur is mandated for all underground equipment used at the Nevada Test Site (NTS). Data regarding the quantification of SO₂ can be found in Appendix A.

Table 3-1. Comparison of Measured Exhaust Constituents to Manufacturer's Exhaust Specifications

Diesel Exhaust Constituent	Engine Exhaust Content per Mfg. Data (ppm)	ENERAC 3000 Values (ppm)
NO _x	130	41.57
CO	110	9.88
CO ₂	32,000	4834*

* Includes a measured background of 369 ppm CO₂

3.2 Retention Parameters

As discussed earlier, the focus of this experiment was to obtain information related to the retention of NO_x in the north ramp. Two approaches to the calculation of NO_x retention are presented. The first uses average diluted and undiluted constituent data in conjunction with calculated dilution rates to establish NO_x retention (TRW, 1994). The second method makes more direct use of the available data by numerically integrating the diluted and undiluted constituent data (corrected for flow rate) and using the calculated areas under the data traces to establish NO_x retention.

3.2.1 Retention Based on Dilution Rate

The design-basis flow rate of the ventilation system was reported as $3,120 \text{ m}^3/\text{min}$ (TRW, 1994). Given that the diesel engine has a reported output of $12.5 \text{ m}^3/\text{min}$, this leads to a design-basis dilution rate of 250:1. The measured air flow rate of the ventilation system at the time of the experiment was $1678 \text{ m}^3/\text{min}$. Therefore, the dilution rate, as tested, was 134:1. Focusing on NO_x retention, the average measurement of undiluted NO_x output from the diesel engine was calculated as 41.57 ppm. The average NO_x output recorded for the ventilation exhaust line was 0.0746 ppm. Combining these values with the experimentally determined ventilation flow rate leads to a NO_x retention of 76% within the north ramp.

3.2.2 Retention Based on Integrated Data

The use of averages to calculate NO_x retention has the implied assumption that the source of the emissions (i.e., the locomotive) is in continuous operation in the tunnel during the duration of the test. For this experiment, diesel emissions were introduced into the north ramp during three distinct stages of the experiment. Thus, a more appropriate method for calculating NO_x retention is to compare the integrated diluted and undiluted data for NO_x . Figure 3-1 shows the data traces for the diluted and undiluted NO_x readings (corrected for flow rate) along with the calculated areas under each curve. The integration of the data traces was accomplished using the Trapezoidal Rule of planar area approximation. For this approach, a NO_x retention of 61% is calculated.

Integrated Area for Undiluted NO_x = 87,671 ppm-m³
Integrated Area for Diluted NO_x = 34,487 ppm-m³

NO_x Retention = 61 %

Figure 3-1. Undiluted and diluted NO_x data and integrated values.

Gaps exist in the diluted and undiluted NO_x data that could bias the calculated retention values. First, there is a 20 minute period at the start of Stage 1 during which the locomotive was at idle in the tunnel and the ENERACTM 3000 was not collecting data. Thus, some of the diesel exhaust constituents introduced during Stage 1 cannot be quantified or accounted for in the retention calculations. Similarly, at the end of Stage 3, sampling of the diluted exhaust constituents removed by the ventilation system was halted prematurely. Consequently, due to a lack of data at the beginning of Stage 1 and at the end of Stage 3, there is some error in the reported retention rates. Since the missing data are related to an idling period for the engine and a period when constituent removal through the vent line was much diminished, it is assumed that the introduced error is small.

4.0 DISCUSSION AND RECOMMENDATIONS

The results of the measurements described in this report suggest that calculations based upon the assumption of 100% NO_x retention within the tunnel may be overly conservative. Evaluation of two methods for calculating total retention indicate ranges between 61% and 76%. These results, based on data reported here, are somewhat uncertain and possibly prone to errors on the conservative side because of factors discussed in this section.

Based on observations made and data collected during the course of the diesel emissions experiment, recommendations for improved experimental design have been developed. These recommendations focus on the location of the sampling port within the ventilation ductwork and the conduct of site operations during the course of the experiment.

4.1 Experimental Design

4.1.1 Instrumentation

The instrumentation chosen for the experiment appeared to provide adequate resolution of diluted and undiluted diesel constituents with zero instrument failures. Velocity traverse and meteorological measurements were also made with zero instrument failures. Collection of VOC grab samples was performed in accordance with EPA guidelines; however, a number of uncertainties exist due to problems encountered with the vacuum regulator hardware. VOC sample collection normally takes place over a four-hour period. For this experiment, sampling durations were shortened to nominally one hour. The vacuum regulators were unable to precisely control sampling for this reduced period, resulting in VOC sample times of 23 to 60 minutes. Subsequent analysis of the VOC samples indicated that the truncated sample times did not unduly bias VOC determinations; however, the regulator problems should be resolved prior to any future sampling.

4.1.2 Dilute Constituent Sampling

Based on EPA methods, sampling ports within a duct are required to be two diameters upstream of any flow disturbance such as a bend, expansion, or constriction. For the experiment, this required that the sampling port be located on the suction side of the main axial ventilation fan. Because the axial fan created a negative pressure within the ventilation ductwork of at least 6 in of water, air flow to the sample manifold had to be forced by applying a vacuum of 9 in of water to the downstream side of the sample manifold (Figure 2-4).

Results of exhaust ventilation line sampling suggest that the application of this vacuum to the sample manifold stressed the connections within the dilute constituent sampling system enough to cause leaks. Figure 4-1 shows that large amounts of SO_2 were found at certain times within the ventilation exhaust samples. However, since the locomotive was powered by low sulfur fuel (per NTS requirements), it could not have been the source of the SO_2 . A more likely source would be gasoline powered equipment operating outside the tunnel portal. Since SO_2 from these sources may have been drawn into the tunnel from the outside, the presence of the gas in the sampled air stream does not necessarily indicate leaks in the sample manifold system. However, VOC samples suggest such a probability. VOC samples taken from the sample manifold show high levels of propane (up to 313 ppb); however, VOC samples taken within the tunnel show only 1 to 2 ppb of propane, indicating either a potential source of propane within the tunnel downstream from the test location, or the possible contamination of the samples from a source within the instrumentation trailer. A survey of material used within the tunnel during the experiment suggests that potential sources did exist (e.g., aerosols, paints, lubricants, degreasers, cigarette lighters, and acetylene gas welding equipment), but it is believed that these sources cannot account for the propane levels detected in the VOC canisters. However, a test of the instrumentation trailer found background levels of propane consistent with the measured levels in the VOC canisters. When taken in conjunction with the SO_2 data, an unquantifiable leak within the sample manifold assembly is indicated.

The implications of this leak are that:

- although propane levels cannot be quantified, levels are likely lower than indicated in the VOC analyses.
- other VOCs in the tunnel may be slightly higher or lower than measured.

(a)

(b)

TRI-6313-57-0

Figure 4-1. Runs 1, 2, and 3 sulfur dioxide values measured (a) inside the ventilation duct and (b) at the locomotive exhaust.

- ventilation exhaust constituent concentrations would likely be higher than measured.
- tunnel retention rates are likely to be lower than reported.

Given that the root cause of the leak is the vacuum applied to the sample manifold, an examination of the EPA standards was warranted. The two-diameter placement requirement used to site the sampling port in the ventilation ductwork is intended for monitoring in relatively short runs of ductwork or for use in monitoring particulate-laden airstreams. Since the ventilation ductwork at the ESF is not short and particulate monitoring was not an aspect of this experiment, it is believed that the sampling port could have been located on the positive pressure side of the ventilation fan without adversely affecting the accuracy of the experiment. Such a sampling probe placement would have eliminated the need for the vacuum pump on the sample manifold and would have likely eliminated all attendant problems attributed to the stresses introduced by the vacuum pump on the system.

4.2 Site Operations

Because the experiment had to be conducted during a scheduled maintenance shift, activities occurring within the tunnel increased the uncertainties associated with the results of the experiment. If this experiment were to be repeated, the following controls on site operations are suggested:

- All aerosol material entering the tunnel should be inventoried at the beginning and end of work shifts.
- All activities involving maintenance/mining in the underground should be curtailed for at least four hours prior to the start of the test, and should not resume until data collection is complete.
- All personnel and equipment, with the exception of those personnel and materials associated with the test, should be kept out of the tunnel for at least two hours prior to the start of the test and remain out for the duration of the experiment.
- All operating motorized equipment should be kept at least 500 m from the portal during the ventilation experiment to prevent contamination of tunnel inlet air at the portal.

5.0 REFERENCES

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APPENDIX A

Samples Taken Inside Ventilation Duct

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Table A1. Samples Taken Inside Ventilation Duct

Elapsed Test Time (minutes)	NOX (ppm)	NO (ppm)	NO ₂ (ppm)	CO (ppm)	CO ₂ (ppm)	SO ₂ (ppb)	Comments
0.0	0.004	0.004	0.005	-0.085	457.9	-2.357	
5.0	0.016	0.002	0.010	-0.097	535.3	-2.127	
10.0	0.016	0.002	0.012	-0.093	531.3	-2.114	
15.0	0.013	-0.002	0.005	-0.082	472.6	-2.112	
20.0	0.011	0.002	0.007	-0.087	462.0	-2.831	Train In
25.0	0.046	0.027	0.017	-0.088	442.8	-2.182	
30.0	0.089	0.057	0.026	-0.081	485.2	-3.595	
35.0	0.063	0.034	0.028	-0.086	526.5	-3.182	
40.0	0.036	0.016	0.018	-0.093	558.6	-3.624	
45.0	0.057	0.034	0.023	-0.045	501.0	-1.854	
50.0	0.054	0.029	0.019	-0.018	505.5	-1.931	
55.0	0.025	0.010	0.013	-0.028	535.5	-2.845	
60.0	0.009	0.000	0.011	-0.050	463.9	-3.054	
65.0	0.004	-0.004	0.006	-0.092	454.6	-1.823	
70.0	0.054	0.030	0.018	-0.085	445.8	-3.131	
75.0	0.063	0.041	0.021	-0.110	450.3	-4.211	
80.0	0.073	0.051	0.025	-0.114	474.2	-2.728	
85.0	0.076	0.057	0.028	-0.114	483.5	-3.575	
90.0	0.040	0.022	0.021	-0.091	462.0	-3.352	
95.0	0.054	0.028	0.019	-0.091	435.8	-2.015	Train Out
100.0	0.049	0.025	0.015	-0.147	505.8	-3.293	
105.0	0.268	0.235	0.040	-0.149	541.2	-3.703	
110.0	0.257	0.219	0.041	-0.127	569.2	-3.357	
115.0	0.145	0.107	0.028	-0.138	481.9	-3.379	
120.0	0.095	0.061	0.024	-0.136	524.8	-3.820	Train In
125.0	0.074	0.041	0.023	-0.126	559.0	-3.712	
130.0	0.058	0.040	0.024	-0.092	542.7	-3.816	
135.0	0.119	0.084	0.033	-0.130	530.7	-4.147	
140.0	0.107	0.074	0.027	0.335	808.0	722.000	
145.0	0.184	0.147	0.028	0.201	567.0	735.000	
150.0	0.129	0.100	0.031	0.178	534.1	747.000	
155.0	0.109	0.073	0.025	0.185	497.4	758.000	
160.0	0.123	0.085	0.030	0.163	456.8	771.000	
165.0	0.104	0.064	0.026	0.094	560.3	777.000	
170.0	0.120	0.083	0.031	0.193	481.1	789.000	
175.0	0.127	0.084	0.023	0.425	419.0	775.000	
180.0	0.121	0.083	0.034	0.270	531.4	412.900	
185.0	0.087	0.047	0.025	0.660	601.7	139.900	Train Out

NOTE: Negative numbers represent zero measurements

Table A1. Samples Taken Inside Ventilation Duct

Elapsed Test Time (minutes)	NOX (ppm)	NO (ppm)	NO ₂ (ppm)	CO (ppm)	CO ₂ (ppm)	SO ₂ (ppb)	Comments
190.0	0.080	0.060	0.030	0.709	625.1	1.028	
195.0	0.066	0.044	0.026	0.623	693.9	1.348	
200.0	0.084	0.044	0.023	0.567	767.0	-0.126	
205.0	0.096	0.069	0.025	6.602	778.0	-0.252	
210.0	0.074	0.043	0.028	39.440	781.0	-0.565	
							Train In
215.0	0.063	0.036	0.020	32.730	793.0	-1.818	
220.0	0.087	0.055	0.021	13.870	810.0	0.282	
225.0	0.056	0.041	0.020	0.461	789.0	0.371	
230.0	0.088	0.064	0.029	0.349	728.0	1.291	
235.0	0.085	0.051	0.025	0.163	983.0	1.732	
240.0	0.056	0.025	0.020	0.088	831.0	2.374	
245.0	0.055	0.024	0.019	0.128	868.0	2.491	
250.0	0.051	0.025	0.026	0.183	457.0	0.479	
255.0	0.025	0.006	0.013	0.083	382.3	2.625	
260.0	0.023	0.008	0.005	0.049	494.7	1.580	
265.0	0.013	0.008	0.017	-0.016	428.0	1.888	
270.0	0.026	0.014	0.016	-0.075	410.9	1.893	
							Train Out

NOTE: Negative numbers represent zero measurements

APPENDIX B

Diesel Emissions Exhaust Sampling

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Table B-1. Diesel Emissions Exhaust Sampling

Elapsed Test Time (minutes)	NOX (ppm)	NO (ppm)	NO ₂ (ppm)	CO (ppm)	CO ₂ (%)	SO ₂ (ppm)	Comments
15.45	0.0	0.0	0.0	0.0	0.1	0.0	
16.23	2.3	2.2	0.1	0.0	0.2	0.0	
17.23	22.8	16.8	5.6	12.6	0.3	0.0	
18.23	29.4	20.5	8.9	21.7	0.3	0.0	
19.23	29.9	21.2	8.7	21.9	0.3	0.0	
20.23	32.6	22.5	9.6	22.8	0.4	0.0	Train In
21.23	27.1	17.5	9.4	22.5	0.3	0.0	
22.25	30.6	20.4	9.9	24.2	0.4	0.0	
23.25	39.7	30.1	8.7	48.1	0.6	0.0	
24.23	42.5	35.4	6.1	30.1	0.6	0.0	
25.25	44.6	38.5	5.1	25.1	0.6	0.0	
26.25	46.5	40.6	5.0	25.6	0.6	0.0	
27.25	47.5	41.6	5.0	19.5	0.6	0.0	
28.25	21.1	19.3	1.5	8.2	0.3	0.0	
29.23	26.5	23.9	2.4	0.9	0.3	0.0	
30.23	30.2	25.8	4.3	5.4	0.3	0.0	
31.23	32.7	27.6	5.0	6.1	0.3	0.0	
32.23	31.3	26.9	4.2	11.1	0.5	0.0	
33.23	32.6	28.9	3.6	14.7	0.5	0.0	
34.25	31.6	28.6	3.0	14.0	0.5	0.0	
35.23	31.5	29.0	2.5	14.2	0.5	0.0	
36.23	29.0	29.0	0.0	12.5	0.5	0.0	
37.23	29.1	29.1	0.0	14.6	0.5	0.0	
38.23	30.0	30.0	0.0	12.8	0.5	0.0	
39.23	29.0	29.0	0.0	12.1	0.5	0.0	
40.23	29.0	29.0	0.0	12.0	0.5	0.0	
41.23	28.2	28.2	0.0	11.1	0.5	0.0	
42.23	26.8	26.8	0.0	11.2	0.5	0.0	
43.23	30.1	30.1	0.0	12.1	0.5	0.0	
44.23	31.0	31.0	0.0	12.2	0.5	0.0	
45.23	31.0	31.0	0.0	13.6	0.5	0.0	
46.25	30.9	30.9	0.0	12.0	0.5	0.0	
47.25	31.0	31.0	0.0	12.1	0.5	0.0	
48.23	31.0	31.0	0.0	12.2	0.5	0.0	
49.23	31.0	31.0	0.0	13.1	0.5	0.0	
50.23	31.1	31.1	0.0	11.0	0.5	0.0	
51.23	31.3	31.3	0.0	10.0	0.5	0.0	
52.23	31.0	31.0	0.0	11.9	0.5	0.0	
53.23	30.5	30.5	0.0	9.7	0.5	0.0	
54.23	30.0	30.0	0.0	9.2	0.5	0.0	
55.25	30.0	30.0	0.0	10.5	0.5	0.0	
56.25	30.0	30.0	0.0	9.1	0.5	0.0	

Table B-1. Diesel Emissions Exhaust Sampling

Elapsed Test Time (minutes)	NOX (ppm)	NO (ppm)	NO ₂ (ppm)	CO (ppm)	CO ₂ (%)	SO ₂ (ppm)	Comments
57.23	30.0	30.0	0.0	8.9	0.5	0.0	
58.23	30.4	30.4	0.0	10.9	0.5	0.0	
59.25	30.0	30.0	0.0	9.5	0.5	0.0	
60.25	30.0	30.0	0.0	9.1	0.5	0.0	
61.25	30.6	30.6	0.0	11.7	0.5	0.0	
62.25	28.1	28.1	0.0	9.0	0.4	0.0	
63.25	29.6	29.6	0.0	8.9	0.5	0.0	
64.25	29.2	29.2	0.0	9.7	0.4	0.0	
65.23	28.8	28.8	0.0	9.9	0.4	0.0	
66.25	29.7	29.7	0.0	9.9	0.4	0.0	
67.25	29.4	29.4	0.0	9.0	0.4	0.0	
68.25	28.6	28.6	0.0	9.1	0.4	0.0	
69.25	28.0	28.0	0.0	8.9	0.4	0.0	
70.25	29.3	29.3	0.0	10.7	0.4	0.0	
71.25	29.8	29.8	0.0	9.0	0.4	0.0	
72.23	29.8	29.8	0.0	10.5	0.4	0.0	
73.23	28.6	28.6	0.0	9.6	0.4	0.0	
74.23	28.9	28.9	0.0	9.0	0.4	0.0	
75.23	29.0	29.0	0.0	8.8	0.4	0.0	
76.25	29.6	29.6	0.0	9.4	0.4	0.0	
77.23	30.0	30.0	0.0	9.0	0.4	0.0	
78.23	30.0	30.0	0.0	9.0	0.4	0.0	
79.25	30.0	30.0	0.0	8.9	0.4	0.0	
80.25	30.4	30.4	0.0	9.0	0.4	0.0	
81.23	28.1	28.1	0.0	8.8	0.4	0.0	
82.25	28.0	28.0	0.0	8.9	0.4	0.0	
83.25	28.0	28.0	0.0	8.6	0.4	0.0	
84.23	28.8	28.8	0.0	8.9	0.4	0.0	
85.23	28.7	28.7	0.0	9.0	0.4	0.0	
86.25	30.0	30.0	0.0	9.4	0.4	0.0	
87.25	29.4	29.4	0.0	9.6	0.4	0.0	
88.23	29.0	29.0	0.0	8.9	0.4	0.0	
89.25	30.4	30.4	0.0	8.9	0.4	0.0	
90.25	58.1	53.1	4.7	15.2	0.7	0.0	
							Train Out
91.23	72.8	65.1	7.3	22.5	0.9	0.0	
92.23	80.7	70.9	9.0	30.7	0.9	0.0	
							Train In
123.97	31.0	25.0	6.0	9.0	0.2	0.0	
124.88	33.4	26.2	6.6	13.2	0.3	0.0	
125.90	39.9	32.8	6.2	21.0	0.5	0.0	
126.90	43.2	37.1	5.2	20.9	0.5	0.0	
127.90	48.1	42.0	5.5	20.6	0.5	0.0	

Table B-1. Diesel Emissions Exhaust Sampling

Elapsed Test Time (minutes)	NOX (ppm)	NO (ppm)	NO ₂ (ppm)	CO (ppm)	CO ₂ (%)	SO ₂ (ppm)	Comments
128.90	52.5	46.3	6.0	23.4	0.6	0.0	
129.90	51.9	46.0	5.8	18.0	0.5	0.0	
130.90	52.4	46.9	5.3	18.1	0.5	0.0	
131.90	53.0	48.0	5.0	18.0	0.5	0.0	
132.90	53.0	48.0	5.0	17.3	0.5	0.0	
133.90	53.3	47.7	5.3	18.5	0.5	0.0	
134.90	53.0	48.0	5.0	17.4	0.6	0.0	
135.90	53.0	48.0	5.0	15.8	0.5	0.0	
136.90	54.1	48.3	5.0	15.8	0.5	0.0	
137.90	54.4	48.0	5.6	16.8	0.5	0.0	
138.90	54.1	48.2	5.0	16.0	0.5	0.0	
139.90	53.0	47.0	5.0	15.0	0.5	0.0	
140.90	53.0	47.0	5.0	15.0	0.5	0.0	
141.90	53.1	47.2	5.0	15.4	0.5	0.0	
142.90	53.7	47.8	5.0	16.8	0.5	0.0	
143.90	53.4	47.0	5.5	18.3	0.5	0.0	
144.90	53.4	47.5	5.0	16.9	0.5	0.0	
145.90	54.9	48.9	5.0	17.6	0.5	0.0	
146.90	54.1	48.4	5.0	16.2	0.5	0.0	
147.90	55.0	49.0	5.1	17.7	0.5	0.0	
148.88	55.0	49.0	5.0	16.5	0.5	0.0	
149.88	55.0	49.0	5.3	15.9	0.5	0.0	
150.88	55.0	49.0	5.0	18.4	0.5	0.0	
151.90	55.0	49.0	5.0	17.4	0.5	0.0	
152.88	55.2	49.0	5.4	17.4	0.5	0.0	
153.88	55.0	49.0	5.1	17.2	0.5	0.0	
154.88	55.0	49.0	5.0	18.4	0.5	0.0	
155.88	55.0	49.0	5.0	23.4	0.5	0.0	
156.88	53.3	47.3	5.0	17.6	0.5	0.0	
157.90	53.7	47.9	5.1	16.3	0.5	0.0	
158.90	53.5	47.8	5.0	16.6	0.5	0.0	
159.88	53.7	48.1	5.0	15.1	0.5	0.0	
160.88	53.4	47.6	5.0	16.2	0.5	0.0	
161.90	55.0	49.0	5.0	18.8	0.5	0.0	
162.90	55.0	49.0	5.0	17.9	0.5	0.0	
163.90	54.6	48.7	5.0	17.9	0.5	0.0	
164.88	55.0	49.0	5.0	16.3	0.5	0.0	
165.90	54.9	48.9	5.0	16.7	0.5	0.0	
166.90	55.0	49.0	5.1	17.8	0.5	0.0	
167.90	54.6	48.6	5.0	17.8	0.5	0.0	
168.90	53.0	47.0	5.0	15.1	0.5	0.0	
169.88	54.1	48.1	5.0	15.9	0.5	0.0	
170.88	53.8	47.8	5.0	16.8	0.5	0.0	

Table B-1. Diesel Emissions Exhaust Sampling

Elapsed Test Time (minutes)	NOX (ppm)	NO (ppm)	NO ₂ (ppm)	CO (ppm)	CO ₂ (%)	SO ₂ (ppm)	Comments
171.88	53.5	47.5	5.0	15.0	0.5	0.0	
172.88	55.0	49.0	5.0	16.3	0.5	0.0	
173.90	54.8	48.8	5.0	16.6	0.5	0.0	
174.90	54.7	48.7	5.0	16.9	0.5	0.0	
175.90	54.9	48.9	5.1	18.0	0.5	0.0	
176.88	55.0	49.0	5.0	18.7	0.5	0.0	
177.90	55.0	49.0	5.0	17.9	0.5	0.0	
178.90	54.7	48.7	5.0	18.5	0.5	0.0	
179.88	53.8	47.8	5.0	17.1	0.5	0.0	
180.88	54.6	48.6	5.0	17.6	0.5	0.0	
181.90	54.7	48.7	5.0	18.3	0.5	0.0	
182.90	53.6	47.7	5.0	15.6	0.5	0.0	
183.88	53.3	47.3	5.0	18.0	0.5	0.0	
							Train Out
							Train In
218.08	0.0	0.0	0.0	0.0	0.1	0.0	
218.78	10.1	9.6	0.5	0.0	0.1	0.0	
219.80	30.2	24.0	5.4	8.1	0.1	0.0	
220.80	31.0	25.1	5.0	12.6	0.2	0.0	
221.78	36.3	31.4	4.1	13.6	0.3	0.0	
222.78	39.0	34.0	4.0	14.9	0.4	0.0	
223.82	39.9	35.3	4.0	14.5	0.4	0.0	
224.82	40.0	36.0	4.0	15.8	0.4	0.0	
225.82	40.0	36.0	4.0	13.7	0.4	0.0	
226.82	40.0	36.0	4.0	12.0	0.4	0.0	
227.82	40.0	36.0	4.0	11.9	0.4	0.0	
228.82	40.0	36.0	4.0	12.0	0.4	0.0	
229.82	40.0	36.0	4.0	12.3	0.4	0.0	
230.82	40.6	36.5	4.0	12.4	0.4	0.0	
231.83	41.0	36.7	4.0	12.6	0.4	0.0	
232.83	42.0	37.8	4.0	12.0	0.4	0.0	
233.85	42.0	38.0	4.0	11.9	0.4	0.0	
234.85	42.0	38.0	4.0	11.9	0.4	0.0	
235.87	42.0	38.0	4.0	11.9	0.4	0.0	
236.87	42.1	38.0	4.0	12.1	0.4	0.0	
237.88	43.0	38.4	4.0	12.8	0.4	0.0	
238.88	42.0	38.0	4.0	12.5	0.4	0.0	
239.90	42.0	38.0	4.0	13.8	0.4	0.0	
240.90	42.9	38.3	4.0	14.5	0.4	0.0	
241.90	42.5	37.6	4.0	14.7	0.4	0.0	
242.90	42.0	37.0	4.0	11.9	0.4	0.0	
243.92	42.2	37.2	4.0	12.0	0.4	0.0	
244.92	42.4	37.5	4.0	12.0	0.4	0.0	

Table B-1. Diesel Emissions Exhaust Sampling

Elapsed Test Time (minutes)	NOX (ppm)	NO (ppm)	NO ₂ (ppm)	CO (ppm)	CO ₂ (%)	SO ₂ (ppm)	Comments
245.93	42.1	37.1	4.0	12.0	0.4	0.0	
246.92	42.0	37.0	4.0	12.3	0.4	0.0	
247.93	42.0	37.0	4.0	12.0	0.4	0.0	
248.95	42.8	37.9	4.0	11.9	0.4	0.0	
249.97	42.6	37.8	4.0	11.9	0.4	0.0	
250.98	42.0	37.0	4.0	12.0	0.4	0.0	
252.00	42.0	37.0	4.0	12.0	0.4	0.0	
253.02	42.0	37.0	4.0	12.0	0.4	0.0	
254.03	42.0	37.0	4.0	12.1	0.4	0.0	
255.05	42.0	37.0	4.0	12.0	0.4	0.0	
256.07	42.0	37.0	4.0	12.2	0.4	0.0	
257.08	42.0	37.0	4.0	12.2	0.4	0.0	
258.07	42.0	37.0	4.0	12.1	0.4	0.0	
259.10	42.0	37.0	4.0	12.0	0.4	0.0	
260.10	42.0	37.0	4.0	12.1	0.4	0.0	
261.13	42.2	37.4	4.0	13.2	0.4	0.0	
262.15	42.0	37.0	4.0	13.6	0.3	0.0	
263.15	42.1	37.3	4.0	12.1	0.4	0.0	
264.17	42.6	37.8	4.0	12.6	0.3	0.0	
265.18	44.0	39.0	4.0	13.0	0.4	0.0	
266.20	42.4	37.5	4.0	12.7	0.4	0.0	
267.20	43.9	39.0	4.0	12.0	0.4	0.0	
268.22	43.5	38.8	4.0	12.3	0.4	0.0	
269.20	44.0	39.0	4.0	12.0	0.3	0.0	
270.23	44.0	39.0	4.0	12.1	0.3	0.0	
							Train Out
271.22	44.0	39.0	4.0	11.9	0.3	0.0	
272.22	44.0	39.0	4.0	12.7	0.3	0.0	
273.22	44.0	39.0	4.0	12.0	0.3	0.0	
274.25	44.0	39.0	4.0	12.0	0.3	0.0	
275.23	43.3	38.5	4.0	12.0	0.3	0.0	
276.23	43.9	39.0	4.0	11.9	0.3	0.0	
277.23	44.0	39.0	4.0	12.0	0.3	0.0	
278.23	43.4	38.8	4.0	12.2	0.3	0.0	
279.25	43.0	38.3	4.0	12.0	0.3	0.0	

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APPENDIX C

Tunnel Meteorology and Air Flow Rate Measurements

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AIR QUALITY DEPARTMENT 7575
YUCCA MOUNTAIN PROJECT
TUNNEL METEOROLOGY AND AIR FLOW RATE MEASUREMENTS

Observer Lewis MacLennan

Floor → Probe = 27.7"

Date 4/28/95

TIME	TEMPERATURE °C	RELATIVE HUMIDITY %	BAROMETRIC PRESSURE in. Hg
13:45 PST	22.6°C	24%	26.139 in Hg

Looking toward opening of tunnel, starting
on left side

TIME	PERCENT	APPOX. LOCATION	FLOOR TO TOP	SIDE TO SIDE
	4.4%	1 ft. 5 in.	(-43) - .76 * m/s	.34 - 1.61 m/s
	14.6%	4 ft. 8 in.	still - .56 m/s	.32 - 1.4 m/s
	29.6%	9 ft. 6 in.	(-.32) - .56 * m/s	.28 - .58 .42 = Avg ✓ m/s
	50%	16 ft. 0 in.	.23 - .48 m/s	calm - .54 * m/s
	70.4%	22 ft. 6 in.	.34 - 1.26 m/s	calm - 1.0 m/s
	85.4%	27 ft. 0 in.	cannot be taken m/s	*Calm - .60 m/s
	95.6%	30 ft. 7 in.	" " " m/s	m/s
			m/s	m/s
			m/s	m/s

* Flow reversal - air moving out of tunnel for ~ 10 sec

✓ Fairly steady reading ~ 2 min

1410 Train into tunnel / 14:32 Train out of tunnel / 14:35 Train in / 14:52 out
note -- at track level, frequent flow reversal (-.33) + .35 m/s

AIR QUALITY DEPARTMENT 7575
YUCCA MOUNTAIN PROJECT
TUNNEL METEOROLOGY AND AIR FLOW RATE MEASUREMENTS

Observer Don Hamilton

Date 4/28/95

TIME	TEMPERATURE °C	RELATIVE HUMIDITY %	BAROMETRIC PRESSURE In. Hg
14:45 PST	23.4	76%	26.085

TIME					
PERCENT	APPOX. LOCATION		FLOOR TO TOP		SIDE TO SIDE
4.4%	1 ft. 5 in.	10"	.78	m/s	12.5" .50 m/s
14.6%	4 ft. 8 in.	33"	.75	m/s	41.5" .52 m/s
29.6%	9 ft. 6 in.	67" 5.7"	.79	m/s	85" .65 m/s
50%	16 ft. 0 in.	113" 9.5"	.73	m/s	111.0" .66 m/s
70.4%	22 ft. 6 in.	141.2"	.43	m/s	16.7" .51 m/s
85.4%	27 ft. 0 in.	16.0	.41	m/s	20.2" .47 m/s
95.6%	30 ft. 7 in.	18.0	.45	m/s	22.7" .47 m/s
				m/s	
				m/s	

**YUCCA MOUNTAIN
ESF VENTILATION SYSTEM VELOCITY TRAVERSE**

Operator(s) Ren Hamilton Date 4-28-95 Time 13:00

Stack Diameter or Dimensions (in.) 66" Pitot Tube ID No. 160-60

Bar. Pres. (in. Hg) 26.161 Temperature (°C) 20 Rel. Humidity (%) 34%

Comments _____

Traverse Point No.	Velocity Hd., Δp (in. H ₂ O)	Actual Air Velocity (ft./min.)
From Far End (in.)		<u>2125</u>
1 <u>28 6"</u>	<u>.25</u>	<u>2125</u>
2 <u>28 10"</u>	<u>.31</u>	<u>2325</u>
3 <u>18 5 20"</u>	<u>.58</u>	<u>2600</u>
4 <u>33.0</u>	<u>.42</u>	<u>2750</u>
5 <u>46.5</u>	<u>.39</u>	<u>2650</u>
6 <u>56.4</u>	<u>.34</u>	<u>2450</u>
7 <u>63.1 60"</u>	<u>.28</u>	<u>2250</u>
From Top (in.)		
8 <u>28 6"</u>	<u>.26</u>	<u>2155</u>
9 <u>28 10"</u>	<u>.3</u>	<u>2325</u>
10 <u>18 5 20"</u>	<u>.57</u>	<u>2555</u>
11 <u>33.0</u>	<u>.38</u>	<u>2600</u>
12 <u>46.5</u>	<u>.37</u>	<u>2555</u>
13 <u>56.4</u>	<u>.32</u>	<u>2400</u>
14 <u>63.1 60"</u>	<u>.26</u>	<u>2155</u>

**YUCCA MOUNTAIN
ESF VENTILATION SYSTEM VELOCITY TRAVERSE**

Operator(s) Ren Hamilton Date 7-29-95 Time 14:45

Stack Diameter or Dimensions (in.) 66" Pitot Tube ID No. 160-60

Bar. Pres. (in. Hg) 26.108 Temperature (°C) 23.4 Rel. Humidity (%) 30%

Comments _____

Traverse Point No.	Velocity Hd., Δp (in. H ₂ O)	Actual Air Velocity (ft./min.)
From Far End (in.)		
1 28'6"	.25	2150
2 38'10"	.31	2350
3 48'20"	.38	2650
4 33.0	.41	2750
5 46'8"	.38	2650
6 56'4"	.34	2500
7 63'60"	.29	2325
From Top (in.)		
8 28'6"	.29	2325
9 38'10"	.35	2550
10 48'20"	.41	2750
11 33.0	.43	2800
12 46'8"	.39	2675
13 56'4"	.33	2455
14 63'60"	.31	2350

APPENDIX D

VOC Analyses

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Table 1
Summary of Sampling Run Parameters

Site	Canister #	Start Time/Date	Stop Time/Date	Initial Vacuum (in Hg)	Final Vacuum (in Hg)
Tunnel Portal	1941	0950 4/29/95	1047 4/29/95	26.0	8.8
Tunnel Sampling Manifold	1948	1135 4/29/95	1216 4/29/95	26.0	9.0
Tunnel Sampling Manifold	1946	1001 4/29/95	1101 4/29/95	26.0	9.0
Tunnel Sampling Manifold	1956	1315 4/29/95	1347 4/29/95	26.0	8.3
Down Tunnel	1945	0947 4/29/95	1010 4/29/95	25.8	5.0

Start & stop times are based on Mountain Daylight Saving Time

Table 2
Summary of Ambient VOC Sample Results, ppbV
April 29, 1995

SITE	PORTAL	SAMPLE MANIFOLD	SAMPLE MANIFOLD	SAMPLE MANIFOLD	DOWN TUNNEL
CANISTER NO.	1941	1948	1946	1956	1945
ETHYLENE	1.2	0.3	0.7	0.3	8.5
ACETYLENE	1.0	0.3	0.6	ND	7.3
ETHANE	0.9	4.6	3.2	4.3	ND
PROPYLENE	0.5	0.3	0.6	0.2	5.2
PROPANE	1.0	313	163	313	2.0
CHLOROMETHANE	0.3	0.3	0.2	0.2	0.3
DICHLORODIFLUOROMETHANE	0.3	0.2	0.2	0.3	0.3
ISOBUTANE	ND	1.2	0.8	1.0	ND
ISOBUTENE + 1-BUTENE	ND	ND	ND	ND	2.0
1,3-BUTADIENE	ND	ND	ND	ND	0.5
N-BUTANE	0.2	ND	0.5	ND	0.7
METHANOL	32.1	5.6	8.8	6.4	7.9
ETHANOL + ACETONITRILE	751	ND	ND	6.8	ND
ISOPENTANE	ND	0.5	0.8	ND	1.1
TRICHLOROFLUOROMETHANE	0.1	0.2	0.2	0.2	0.1
N-PENTANE	ND	0.2	0.4	0.2	0.8
ISOPRENE	ND	0.2	0.2	0.2	0.2
DIETHYL ETHER + 2-PROPANOL	23	ND	ND	ND	ND
METHYLENE CHLORIDE	ND	ND	ND	ND	0.2
FREON 113	0.06	0.06	0.06	0.06	0.06
3-METHYLPENTANE	0.2	ND	ND	ND	0.2
1-HEXENE	ND	ND	ND	ND	0.2
N-HEXANE	ND	ND	ND	ND	0.3
METHYLCYCLOPENTANE	ND	ND	ND	ND	0.2
1,1,1-TRICHLOROETHANE	0.3	0.05	0.06	0.05	0.04
BENZENE	0.3	0.3	0.4	0.2	1.8
CARBON TETRACHLORIDE	0.06	0.04	0.07	0.05	0.05
ISOHEPTANE + 2,3-DIMETHYLPENTANE	ND	0.4	0.4	0.3	0.2
3-METHYLHEXANE	ND	0.4	0.4	0.3	0.1
1,4-DIOXANE + 2,2,4-TRIMETHYLPENTANE	ND	ND	ND	ND	0.3
N-HEPTANE	ND	0.3	0.3	0.2	0.1
TOLUENE	0.4	0.5	0.9	0.5	1.6
3-METHYLHEPTANE	0.7	ND	ND	ND	ND
HEXANAL	ND	0.3	0.2	0.2	ND
N-OCTANE	ND	0.5	0.4	0.4	ND

Table 2 Cont'd

ETHYLBENZENE	ND	ND	0.2	ND	0.2
P-XYLENE + M-XYLENE	0.2	0.2	0.4	0.2	0.5
O-XYLENE	0.1	0.2	0.2	0.1	0.2
A-PINENE + BENZALDEHYDE	ND	0.2	0.2	ND	ND
M-ETHYLTOLUENE	ND	ND	ND	ND	0.09
1,2,4-TMBENZENE + T-BUTYLBENZENE	ND	0.1	0.2	0.09	0.2
LIMONENE	ND	ND	0.2	ND	ND
UNIDENTIFIED VOC	4.2	2.7	2.5	3.0	4.3
UNIDENTIFIED HALOGENATED	0.2	0.7	0.8	0.9	ND
TNMHC	279	138	78.9	139	22.7

ND = Not Detected

Note: VOCs not appearing on this list were not detected in any canister

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