EVALUATION OF SHORT-TERM EXPOSURES TO THEATRICAL SMOKE AND HAZE

AIR SAMPLING PROTOCOL

Prepared for:

Equity-League Pension and Health Trust Funds
(Sponsor)

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C O N T E N T S

F I G U R E S

T A B L E S

A P P E N D I C E S

EXECUTIVE SUMMARY

This document contains an Air Sampling Protocol for conducting monitoring to evaluate potential exposures to short-term concentrations of smoke and haze special effects in theatrical productions. The purpose of this document is to provide a specific methodology (including calibration procedures for a real-time air monitor) to be used in determining whether air concentrations in areas of a stage exceed the Guidance levels recommended in a recent Health Effects Study (Mt. Sinai and ENVIRON 2000).

The manner in which this Protocol is implemented will depend on the status of the choreography and blocking development:

- For a production in which the blocking has already been established and Actor positions on-stage are already known, this Protocol can be used to determine whether any of these Actors are situated at locations where the Guidance levels would be exceeded.

- For a production in which the blocking has not already been established, this Protocol can be used to develop a map of locations and timing guidelines in order to avoid peak exposures to Actors. The amount of monitoring required for this second scenario would be greater than that required under the first scenario.

No monitoring would be necessary for productions that are able to block their shows in accordance with the Equipment-Based Guidelines developed by ENVIRON (2001).

I. INTRODUCTION

A. Background

In 1997-99, at the request of Actors' Equity Association (AEA) and the League of American Theaters and Producers (LATP) and with the support of the Equity-League Pension and Health Trust Funds, investigators from the Mount Sinai School of Medicine (Mt. Sinai) and ENVIRON International Corporation (ENVIRON) conducted a study to determine whether the use of smoke, haze, and pyrotechnics special effects in theatrical musical productions is associated with a negative health impact in Actors. This effort was initiated in response to ongoing concerns by Actors that the use of these theatrical effects may have an impact on their health. The results of this study were presented in the report *Health Effects Evaluation of Theatrical Smoke, Haze, and Pyrotechnics* (Mt. Sinai and ENVIRON 2000).

The results of the Mt. Sinai/ENVIRON study indicate that there are certain health effects associated with Actors exposed to elevated or peak levels of glycol smoke and mineral oil. However, as long as peak exposures are avoided, Actors' health, vocal abilities, and careers should not be harmed. Pyrotechnics as used on Broadway at the time of the study did not have an observable effect on Actors' health.

Mt. Sinai and ENVIRON recommended the following guidance levels with respect to glycols and mineral oil:

- The use of glycols should be such that an Actor's exposure does not exceed 40 milligrams per cubic meter (mg/m^3).

- Mineral oil should be used in a manner such that an Actor's exposure does not exceed a peak concentration of 25 mg/m^3.

- For chronic exposures to mineral oil, the existing standards established for oil mists (5 mg/m^3 as an eight-hour time-weighted average) should also be protective for Actors in theatrical productions.

ENVIRON has prepared a set of two reports that can be used to ensure that Actor exposures do not exceed the guidance levels – an Equipment-Based Guidelines document (ENVIRON 2001) and this Air Sampling Protocol:

- Equipment-Based Guidelines document – The Equipment-Based Guidelines provide conservative Guidelines on the distance (with respect to the discharge point on the equipment) and length of time that concentrations exceeding the peak guidance levels may occur for various use patterns. These Guidelines could be used in staging performances in lieu of conducting stage-specific testing.

- Air Sampling Protocol document – This Air Sampling Protocol provides detailed procedures for conducting theater- and production-specific monitoring. Monitoring conducted in accordance with the Air Sampling Protocol can be used to evaluate potential exposures to short-term concentrations of smoke and haze special effects for theatrical productions where the Equipment-Based Guidelines are not applicable. This includes productions that use smoke/haze equipment or fluids other than those for which Equipment-Based Guidelines have been provided in this document, or productions that use equipment or fluids that are included in these Equipment-Based Guidelines, but under conditions other than those utilized in developing the Guidelines.

B. Purpose and Objectives

Based on the results of the health effects study, ENVIRON has developed this Air Sampling Protocol for conducting monitoring to evaluate short-term (i.e., immediately following cue release) air concentrations. This Air Sampling Protocol presents the technical approach for conducting monitoring to evaluate potential exposures to short-term concentrations of smoke and haze special effects in theatrical productions. This Protocol consists of the following four chapters:

I. Purpose of the sampling
II. Sampling methodology, including selection of the chemicals to be sampled, sampling equipment, selection of scenes to be sampled, sampling procedures
III. Laboratory analysis
IV. Data analysis

The manner in which this Protocol is implemented will depend on the status of the choreography and blocking development:

- For a production in which the blocking has already been established and Actor positions on-stage are already known, this Protocol can be used to determine whether any of these Actors are situated at locations where the guidance levels would be exceeded.

- For a production in which the blocking has not already been established, this Protocol can be used to develop a map of locations and timing guidelines in order to avoid peak exposures to Actors.

The amount of monitoring required for the second scenario would be greater than that required under the first scenario.

C. Sampling Protocol Overview

The Air Sampling Protocol involves a general procedure for measuring peak concentrations using a real-time personal aerosol monitor that has been properly calibrated for the smoke/haze-generating equipment used in a particular production. This Protocol also

includes a methodology for calibrating the aerosol monitor for various smoke/haze machine-fluid combinations and collecting the measurements necessary to identify potential peak exposures that exceed the guidance levels.

The procedures described in this Protocol should be conducted by an individual with suitable training or experience in industrial hygiene sampling and data analysis.[1] Personnel from ENVIRON can be contacted to discuss or conduct air sampling in accordance with this Protocol at the following addresses:

ENVIRON International Corporation
274 Main Street, P.O. Box 1220
Groton, Massachusetts 01450
978/448-8824 (phone)
978/448-8825 (fax)
Attention: Dr. Alan Kao (akao@environcorp.com)

ENVIRON International Corporation
214 Carnegie Plaza
Princeton, New Jersey 08540
609/452-9000 (phone)
609/452-0284 (fax)
Attention: Dr. Joseph Highland (jhighland@environcorp.com)

Alternatively, a directory of consulting firms with personnel trained in industrial hygiene throughout the United States can be found in the American Industrial Hygiene Association (AIHA) web site (www.aiha.org).

This Protocol has been written to be as explicit as possible. However, certain aspects of the Protocol will require professional judgment in order to conduct the sampling properly (e.g., whether the level of smoke output appears to be "relatively low"). It is advised that experienced theatre personnel familiar with the operation of these smoke/haze machines be consulted in implementing this Protocol.

[1] The person conducting the sampling should be familiar with the general principles of industrial hygiene and the procedures described in this Protocol. As described in this Protocol, the sampling procedure includes the calibration of an aerosol monitor and real-time monitoring using the aerosol monitor. For certain smoke/haze machines and fluids, calibration factors have already been developed (see Equipment-Based Guidelines, ENVIRON 2001), and the calibration step is not necessary. If only monitoring is necessary (i.e., no calibration factors need to be developed), the person conducting the testing should be familiar with the procedures necessary to operate and zero the aerosol monitor. If full testing is conducted (i.e., calibration and monitoring), the person conducting the testing should also be knowledgeable on the procedures for calibrating an air sampling pump, selection and handling of sampling media, selection of laboratories, packaging and shipment of sampling media, and statistical analysis (linear regression).

II. SAMPLING METHODOLOGY

A. Selection of Chemicals to be Sampled

The chemicals used to produce theatrical effects included in this Protocol are (1) glycols for smoke generation, and (2) mineral oil used for a haze effect.

1. Glycols

Mixtures of various glycols are used to generate smoke effects. Glycol aerosols are generated by heating a glycol/water solution and feeding the vapor through a critical flow orifice. The glycol solutions currently used to generate smoke effects consist of mixtures of 1,3-butylene glycol (BG), diethylene glycol (DEG), propylene glycol (PG), dipropylene glycol (DPG), triethylene glycol (TEG), and water. Upon entering the atmosphere, the vapor condenses rapidly to form fine droplets, producing a visible aerosol. The particles subsequently revolatilize into the vapor phase and dissipate.

2. Mineral Oil

A haze-like effect can be produced by generating an aerosol of mineral oil. Oil mist effects are generated by "cracking" a USDA approved food or pharmaceutical grade mineral oil through a dispersion system using high-pressure air. Haze machines ("hazers") typically produce a fairly uniform particle size distribution with aerodynamic diameters ranging from 0.1 to 1.0 micrometers (μm). The haze particles will dissipate via room ventilation.

While other chemicals may be available currently or in the future for generating smoke and haze effects (e.g., glycerol), these chemicals were not included in the Mt. Sinai/ENVIRON study. Thus, the conclusions and guidance levels developed from the Mt. Sinai/ENVIRON study will not necessarily be applicable to these alternative chemicals. Comparable guidance levels could be developed for alternative chemicals upon request through an appropriate health effects evaluation.

B. Sampling Equipment and Materials

Monitoring of short-term concentrations will be performed using portable real-time aerosol monitors. This Protocol is based on the use of a *personal*DataRAM Model PDR-1000 manufactured by Monitoring Instruments for the Environment, Inc. (MIE).[2] The PDR-1000 is a high sensitivity nephelometric (i.e., photometric) monitor that uses a light scattering sensing chamber to measure the concentration of airborne particulate matter (liquid or solid), providing a direct and continuous readout as well as electronic logging of the data.

[2] The PDR-1000 aerosol monitor can be purchased directly from MIE (781/275-1919 or www.mieinc.com). Alternatively, PDR-1000 aerosol monitors can be rented from Response Ashtead Technology (800/242-3910 or www.ashtead-technology.com).

Glycols. Once generated, glycol aerosols are very dynamic (i.e., changing rapidly with time) with respect to particle size and abundance. The glycols rapidly evaporate from the surface of the droplets, resulting in reduced particle size and, eventually, complete vaporization of the aerosol. Based on equipment testing data collected by ENVIRON, a relatively stable presence of glycol aerosol can be measured while a smoke machine is in operation and for approximately one to two minutes after the smoke is no longer emitted. After this short period of time, the aerosol will have vaporized and will no longer be detectable with an aerosol monitor. However, because this Protocol is designed for measuring short-term concentrations immediately following the release of glycol aerosols from a smoke machine (as opposed to an aged aerosol), the real-time aerosol monitor readings are appropriate surrogates for total glycol levels prior to vaporization.

Mineral oil. Mineral oil mist particles are relatively persistent in the atmosphere, and have a longer "hang time" than glycols. Therefore, the aerosol monitors are appropriate for measuring short-term oil mist levels.

Aerosol monitor calibration. The PDR-1000 aerosol monitors as obtained are typically calibrated to Arizona road dust over a measurement range of 0.001 to 400 mg/m^3. In order to be utilized to measure short-term glycol or oil mist concentrations, the monitors will first need to be calibrated for the smoke or haze machines and fluids being used. Sampling for the calibration will be conducted in general accordance with National Institute for Occupational Safety and Health (NIOSH) methods.

1. Glycols

To calibrate the aerosol monitors for glycols, a variation of NIOSH Method 5523 (NIOSH 1996; Pendergrass 1999) will be used. A full description of Method 5523 is provided in Appendix A. In this method, a sampling pump is used to draw air through an OSHA Versatile Sampler (OVS) trap containing two sections of XAD-7 resin (200-mg front section, 100-mg back section, separated by a polyurethane foam [PUF] plug). The XAD-7 resin will be used to collect both the particulate and vapor phase of the glycol aerosol. A 13-mm glass fiber filter (GFF) plug precedes the front section and a PUF plug follows the back section.

2. Mineral Oil

To calibrate the aerosol monitors for mineral oil mist, a custom NIOSH Method 5026 (NIOSH 1994) will be used. A full description of Method 5026 is provided in Appendix A. In this method, a sampling pump is used to draw air through a 37-mm polyvinyl chloride (PVC) membrane filter (5 μm pore size), which is analyzed by infrared spectrophotometry (IR) in conjunction with a custom bulk oil sample.

C. Selection of Scenes to be Sampled

In order to conduct appropriate testing of a production, the technicians conducting the testing must be familiar with the scenes and cues in which the smoke or haze effects are used. To accomplish this, the technicians should discuss with stage managers or other theater personnel (e.g., head electrician) the specific scenes that involve cue releases and the details of the release (e.g., duration, direction, release height). If possible, the technicians should view a performance of the production (live performance or rehearsal) to understand better the nature of the cue release and to identify Actors who are potentially receiving peak exposures.

D. Sampling Procedures

In addition to the smoke/haze-generating equipment and fluids, the following sampling and monitoring equipment are necessary to conduct the air sampling procedures:

Glycol Sampling

- Three (3) portable real-time aerosol monitors (e.g., MIE pDR-1000) with zeroing bags;
- Three (3) personal sampling pumps capable of providing an air flow rate of 2-3 liters per minute (lpm) (e.g., Gilian GilAir-5, SKC Aircheck Model 224-44XR, or equivalent) and flexible tubing;
- One (1) sampling pump calibrator (e.g., BIOS Drycal or equivalent)
- Three (3) tripods;
- Three (3) OVS traps containing two-section sorbent bed of XAD-7 (e.g., SKC Catalog Number 226-57)
- One (1) small glass vial;
- Cooler and ice packs

Mineral Oil Sampling

- Three (3) portable real-time aerosol monitors (e.g., MIE pDR-1000) with zeroing bags;
- Three (3) personal sampling pumps capable of providing an air flow rate of 2-3 lpm (e.g., Gilian GilAir-5, SKC Aircheck Model 224-44XR, or equivalent) and flexible tubing;
- One (1) sampling pump calibrator (e.g., BIOS Drycal or equivalent)
- Three (3) tripods;
- Three (3) two-piece cassettes preloaded with 37-mm PVC filters

As discussed later in this chapter, additional OVS traps and sampling cassettes will be needed for field and laboratory blanks. Three aerosol monitors should be sufficient for most stages. However, depending on the size of stage and the positioning of the cue release, more than three aerosol monitors and sampling pumps may be necessary. For example, if a particular scene involves numerous drops, scrims, or other stage props that may affect the distribution of the smoke or haze plume, additional monitors should be considered. If more than one type of smoke/haze-generating equipment or fluid are to be tested, the number of sampling media should be increased accordingly.

The sampling is to be conducted in a two-step process. The first step involves collecting sufficient data to calibrate the aerosol monitors for the machine-fluid combination and release configuration of the specific production. The second step involves using the calibrated aerosol monitor either (1) to identify Actors, if any, who might be exposed to peak levels under current blocking or (2) to identify areas on-stage, if any, where exceedances of the guidance levels occur for future blocking development. Under the latter scenario, these measurements would be used to develop a map or guidelines for preventing peak exposures to Actors from occurring (e.g., areas of the stage and periods of time for Actors to avoid following cue release).

1. Aerosol Monitor Calibration

Calibration of the aerosol monitors involves collecting simultaneous measurements with a series of sampling pumps and PDR-1000 aerosol monitors, mounted on tripods. As shown in Figure 1, each tripod assembly should consist of a pump, flexible tubing, sampling media (OVS trap for glycols and cassettes for mineral oil), and an aerosol monitor. The sampling media should be positioned at a 45 degree angle. The height of the tripod should correspond with the breathing zone of a typical Actor (i.e., approximately five feet); if the scene involves Actors lying on the floor or in elevated positions, the monitoring height should be adjusted accordingly.

Glycols

a) Prior to assembling the tripods, calibrate the sampling pumps to 2 lpm using the pump calibrator. Note the calibrated flow rates on the *Pump Calibration* form (Appendix B). Zero the aerosol monitor in accordance with the manufacturer's instructions. Turn on the data logging function of the aerosol monitor and ensure that all data logging times are synchronized.

b) Position the smoke machine on a stand that is can be adjusted to allow a release of smoke at a height of four to five feet. Place the tripods at various distances from the smoke machine release nozzle, ranging from three to 20 feet. The tripods should be placed at interval such that different readings on the aerosol monitor would be expected while the smoke machine is operating. Figure 2 shows an example configuration consisting of six tripods at three-foot intervals from the smoke machine.

c) For machines that have variable release settings, adjust the smoke machine output to a medium setting. Turn on all of the sampling pumps simultaneously five to ten seconds prior to turning on the smoke machine. Turn on the smoke machine, allow sustained smoke generation to occur for 30 seconds, and then turn off the smoke machine. Depending on the level of output from the machine, the smoke generation time can be adjusted upward or downward. For example, if the levels are high enough that the aerosol monitor reaches its maximum reading (i.e., 400 mg/m^3), the smoke generation time can be adjusted downward. If the levels are relatively low, the smoke

generation time can be adjusted upward to ensure that sufficient material is collected on the OVS trap to be detected.

d) Allow the pumps to collect air samples for one minute following the initiation of the smoke generation. After one minute has passed, remove the OVS trap from the tubing and turn off the pump. Due to the short time that the OVS trap will be sampling (i.e., one minute), multiple technicians or assistants may be needed to conduct this sampling (e.g., no more than two pumps for a single technician). Cap the OVS trap and label it so that the type of smoke machine, glycol fluid, sampling location, and other sampling specifics can be identified. In cases where the level of smoke generated is relatively low, the sampling time can be extended for up to two minutes. Sampling should not continue longer than two minutes, as the aerosol will begin to volatilize at this point.

e) After capping and labeling the OVS trap, place it in a cooler with ice packs. Record all information on the calibration run on the *Smoke and Haze Equipment/PDR Calibration* form (Appendix B).

f) If multiple calibration runs are being conducted, allow sufficient time between runs for residual glycols to be removed from the testing area air by room ventilation. This time between runs should be sufficient to allow two air exchanges to occur, which will depend on the ventilation rate but typically is between 15 and 30 minutes.

g) Upon completion of the calibration runs, collect samples of each bulk smoke fluid in small glass vials. Using the pump calibrator, recalibrate the pumps and record the ending flow rates on the *Pump Calibration* form.

h) Submit the OVS traps and bulk fluid to an appropriate laboratory for analysis (see Chapter III). An uncapped, unused OVS trap should also be included as a field blank for every ten samples submitted. A capped, unused OVS trap should also be included as a laboratory blank for every ten samples submitted. To calculate air volumes sampled, use the average of the starting and ending calibrated flow rates for the appropriate pumps.

i) Upon receiving the analytical results, calculate total glycol concentrations as described in Chapter IV.

Mineral Oil

a) Prior to assembling the tripods, calibrate the sampling pumps to 3 lpm using the pump calibrator. Note the calibrated flow rates on the *Pump Calibration* form (Appendix B). Zero the aerosol monitor in accordance with the manufacturer's instructions. Turn on the data logging function of the aerosol monitor and ensure that all data logging times are synchronized.

b) If the hazer has a horizontal release point, position the machine on a stand that is can be adjusted to allow a release of haze at a height of four to five feet. Place the tripods at various distances from the hazer release nozzle, ranging from three to 20 feet. Figure 2 shows an example configuration consisting of six tripods at three-foot intervals from a smoke machine.

c) If the hazer has a vertical and diffused release point (e.g., Rosco Hazemaker, MDG Atmosphere, Reel EFX DF-50), place the hazer on the floor and position tripods at various distances around the hazer. Figure 3 shows an example configuration consisting of six tripods in a three-foot interval grid configuration around the hazer.

d) For machines that have variable release settings, adjust the hazer output to a medium setting. Turn on all of the sampling pumps simultaneously five to ten seconds prior to turning on the hazer. Turn on the hazer, allow sustained haze generation to occur for 30 seconds, and then turn off the hazer. Depending on the level of output from the machine, the haze generation time can be adjusted upward or downward. For example, if the levels are high enough that the aerosol monitor reaches its maximum reading (i.e., 400 mg/m^3), the haze generation time can be adjusted downward. If the levels are relatively low, the haze generation time can be adjusted upward to ensure that sufficient material is collected on the filter to be detected.

e) Allow the pumps to collect air samples for one minute following the initiation of the smoke generation. After one minute has passed, remove the sampling cassette from the tubing and turn off the pump. Cap the sampling cassette and label it so that the type of hazer, mineral oil fluid, sampling location, and other sampling specifics can be identified. In cases where the level of haze generated is relatively low, the sampling time can be extended for up to five minutes.

f) Record all information on the calibration run on the *Smoke and Haze Equipment/PDR Calibration* form (Appendix B).

g) If multiple calibration runs are being conducted, allow sufficient time between runs for residual oil to be removed from the testing area air by room ventilation. This time between runs should be sufficient to allow two air exchanges to occur, which will depend on the ventilation rate but typically is between 15 and 30 minutes. The aerosol monitors should read levels less than 1 mg/m^3 before an additional run is initiated.

h) Upon completion of the calibration runs, collect samples of each bulk mineral oil fluid in small glass vials. Using the pump calibrator, recalibrate the pumps and record the ending flow rates on the *Pump Calibration* form.

i) Submit the sampling cassettes and bulk mineral oil fluid to an appropriate laboratory for a custom mineral oil analysis (see Chapter III). An uncapped, unused cassette should also be included as a field blank for every ten samples submitted. A capped, unused cassette should also be included as a laboratory blank for every ten samples submitted. To calculate air volumes sampled, use the average of the starting and ending calibrated flow rates for the appropriate pumps.

The laboratory results should be used to develop the appropriate calibration factors for the aerosol monitor as described in Chapter IV.

2. Peak Exposure Characterization

After developing the appropriate calibration factors for each smoke or haze machine/fluid combination being used in the production, the aerosol monitor can be used to identify areas on-stage, if any, where exceedances of the guidance levels occur. Each scene involving a cue in which smoke or haze is released should be monitored. The level of monitoring required will depend on the blocking development status:

- For productions in which the blocking has been developed, calibrated aerosol monitors should be placed in locations near the point of release in areas where Actors are situated. The monitors should be left in place as the cue is released and for at least two minutes after the end of the cue.

- For productions in which the blocking has not yet been developed, calibrated aerosol monitors should be placed in locations near the point of release. The monitors should be left in place as the cue is released and for at least two minutes after the end of the cue. These data logged on the aerosol monitor can be used to develop a map or guidelines for preventing peak exposures to Actors from occurring (e.g., areas of the stage and periods of time for Actors to avoid following cue release).

The *Smoke and Haze Equipment Monitoring* form included in Appendix B may be used, if appropriate.

Figure 1. Experimental set-up for aerosol monitor calibration, consisting of a tripod with sampling pump, tubing, and aerosol monitor.

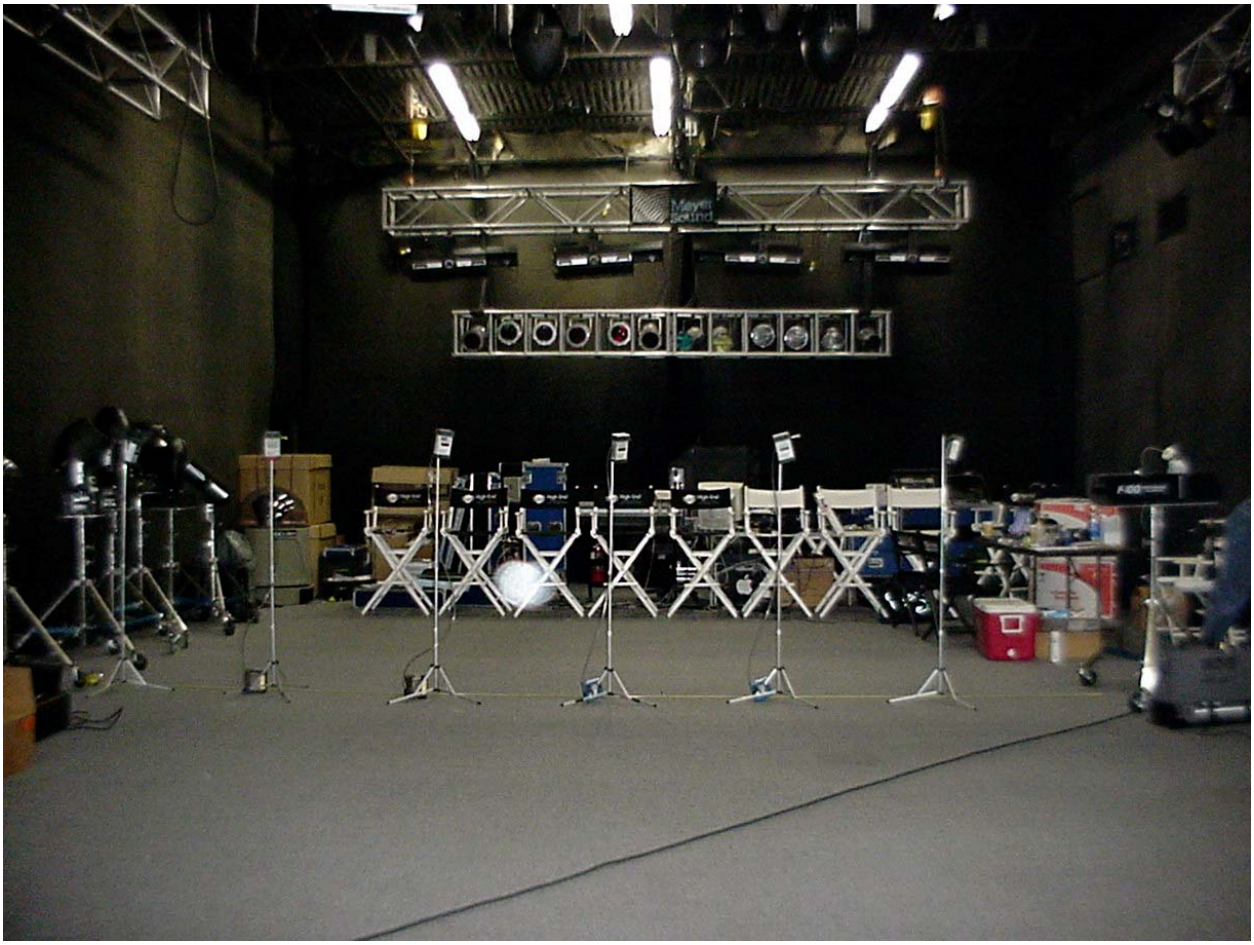

Figure 2. Example sampling configuration consisting of six sampling/monitoring tripods situated at three foot intervals from a smoke machine (far right).

Figure 3. Example sampling configuration consisting of six sampling/monitoring tripods situated at three-foot intervals around a vertical-release hazer (center).

III. LABORATORY ANALYSES

All sample analyses should be conducted by American Industrial Hygiene Association (AIHA) accredited laboratories[3] using validated analytical methodologies.

A. Glycols

Because of the short duration during which the air sample is collected, a low limit of quantitation (LOQ) is required for this Protocol. The standard method for analyzing glycols is NIOSH Method 5523 (see Appendix A). This method involves the use of a gas chromatograph with a flame ionization detector (GC/FID). The method sensitivity reported by NIOSH is between 12 and 48 μg per sample, depending on the individual glycol. These LOQs are higher than are required in order to characterize the stage environment adequately. Based on laboratory-based breakthrough and recovery testing from spiked samples conducted for this study, Method 5523 was extended to a validated LOQ of 4.0 μg of each individual glycol per sample. No breakthrough was observed at flow rates of 2.0 liters per minute (lpm) for up to sixty minutes sampling time. Details of the extended method are provided in Appendix A.

This improved LOQ was validated for propylene glycol, butylene glycol, diethylene glycol, and triethylene glycol. If other glycols are used in a smoke solution (e.g., dipropylene glycol), the laboratory should be consulted regarding the extension of Method 5523 to obtain improved LOQs for these other glycols.

B. Mineral Oil

Mineral oil samples should be analyzed using a custom NIOSH Method 5026 (see Appendix A). This method involves analysis using infrared spectrophotometry, with a bulk mineral oil sample used instead of a stock mineral oil standard. A maximum LOQ of 50 μg per sample should be used.

[3] The analytical methodologies described in this Protocol were validated by Analytics Corporation (formerly LabCorp Analytics Laboratory) of Richmond, Virginia.

IV. DATA ANALYSIS

A. Development of Calibration Curves

1. Glycols

Upon completion of the aerosol monitor calibration sampling, analytical data will be provided for air and bulk glycol samples by the laboratory. The individual glycols detected in the air samples should correspond to the individual glycols identified in the bulk sample. If glycol species are detected in the air that were not measured in the bulk solution, the laboratory should be consulted to determine whether a glycol species has been misidentified on the chromatogram.

After the air sampling data have been appropriately quality checked, total glycol concentrations should be calculated. Only the glycol species measured in the bulk solution should be included. If a glycol species was measured in the bulk solution, but was not detected in the air sample, one half of the detection limit for that glycol species should be used in calculating the total glycol concentration.

To develop a calibration curve, calculate the average aerosol monitor reading during the period of time in which air was drawn through the OVS trap for each air sample. Plot the average aerosol monitor readings against the glycol concentration data. At least three different aerosol monitor readings should be used in developing a calibration curve. The calibration factor is determined from the slope of the regression curve, and can be estimated as follows:

$$C = \frac{OVS}{PDR}$$

where:

C	= aerosol monitor calibration factor, (μg/L)/(mg/m^3)
OVS	= air concentration from OVS trap, μg/L
PDR	= aerosol monitor reading, mg/m^3

An example calibration curve is shown in Figure 4. The data for this curve and the calculated calibration factor are summarized in Table 1.

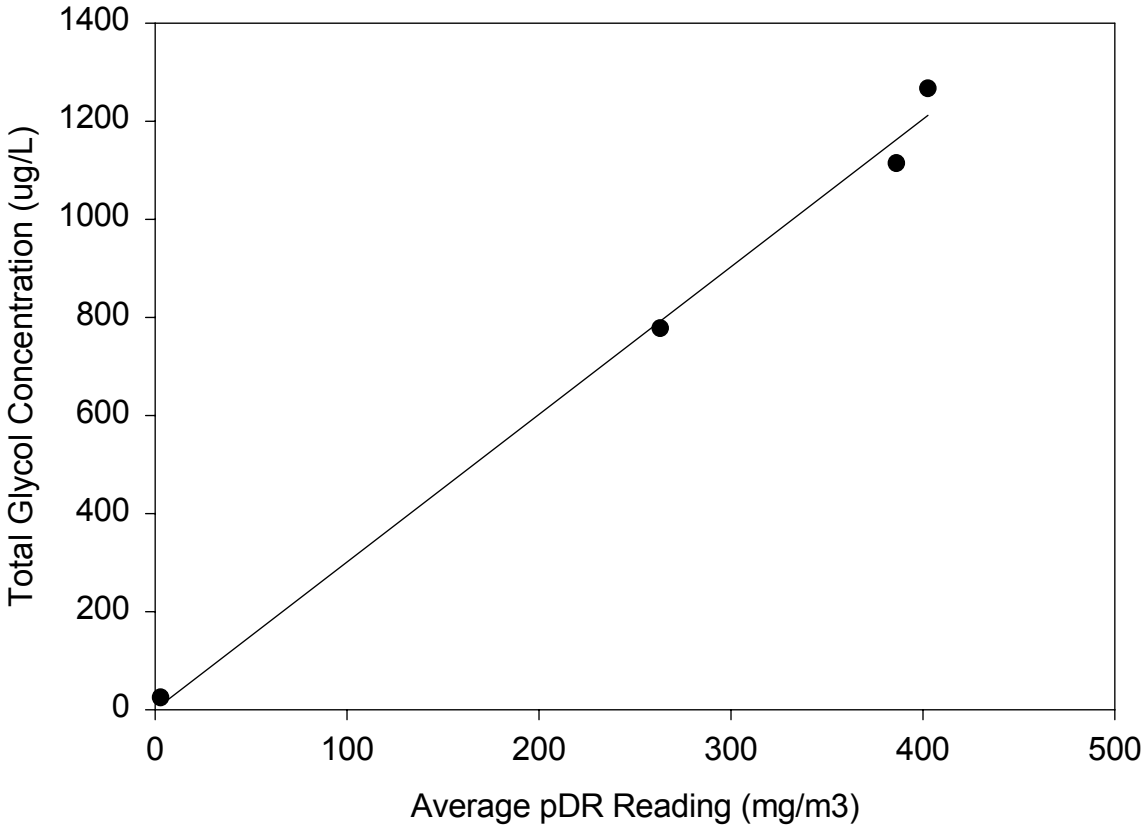

Figure 4. Example calibration curve for glycol monitoring. Slope of calibration curve is 3.01 (μg/L)/(mg/m^3).

TABLE 1 Summary of Data for Example Calibration Factor Calculation			
Distance from Cue Release (ft)	**Average pDR reading (mg/m3)**	**Average Total Glycol Conc. (μg/L)**	**Calibration Factor (μg/L)/(mg/m^3)**
6	403	1,266	3.14
9	386	1,114	2.89
12	263	778	2.96
15	2.8	25	8.9
Average Calibration Factor (from slope of calibration curve)			3.01

2. Mineral Oil

To develop a calibration curve for mineral oil, calculate the average aerosol monitor reading during the period of time in which air was drawn through the sampling cassette for each air sample. Plot the oil mist concentration data against the average aerosol monitor readings. At least three different aerosol monitor readings should be used in developing a calibration curve. The calibration factor is determined from the slope of the regression curve, and can be estimated as follows:

$$C = \frac{OIL}{PDR}$$

where:

C = aerosol monitor calibration factor, (μg/L)/(mg/m^3)
OIL = air concentration of mineral oil mist, μg/L
PDR = aerosol monitor reading, mg/m^3

B. Characterization of Peak Exposures

After developing the appropriate calibration factors for each smoke or haze machine/fluid combination being used in the production, the aerosol monitor can be used as described in Chapter II to identify areas on-stage, if any, where exceedances of the guidance levels occur. The real-time aerosol monitor readings can be converted to glycol or mineral oil concentrations using the calibration factor:

$$CONC = C \times PDR$$

where:

CONC = air concentration of total glycols or mineral oil mist, μg/L
C = aerosol monitor calibration factor, (μg/L)/(mg/m^3)
PDR = aerosol monitor reading, mg/m^3

If peak exposures to Actors are identified upon completion of the measurements, the technicians should meet with the producers of the show to present their findings. At this time, discussions should be held with people involved in the productions regarding the feasibility of various options for avoiding exposures to these peak concentrations, either through changes in the blocking or the configuration of the cue release. Follow-up monitoring should be conducted if the cue release is reconfigured.

V. REFERENCES

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APPENDIX A

Sampling Methodology Documentation

- NIOSH Method 5523: Glycols
- Validated Extension of Method 5523 for Improved Limit of Quantitation
- NIOSH Method 5026: Oil mist, mineral

FORMULA: Table 1 MW: Table 1 CAS: Table 1 RTECS: Table 1

METHOD: 5523, Issue 1 **EVALUATION: PARTIAL** **Issue 1: 15 May 1996**

OSHA : No PEL
NIOSH: No REL
ACGIH: C 50 ppm (ethylene glycol)
(1 ppm = 2.54 mg/m^3 @ NTP)

PROPERTIES: See Table 1

NAMES & SYNONYMS: (1) ethylene glycol: 1,2-ethanediol; (2) propylene glycol: 1,2-propanediol
(3) 1,3-butylene glycol: 1,3-butanediol (4) diethylene glycol: 2-hydroxyethyl ether, 2,2'-oxydiethanol

SAMPLING

SAMPLER: XAD-7 OVS tube (glass fiber filter, 13-mm; XAD-7, 200mg/100mg)

FLOW RATE: 0.5 to 2 L/min

VOL-MIN: 5 L
-MAX: 60 L

SHIPMENT: pack cold for shipment

SAMPLE STABILITY: 28 days @ 5 °C [1]
ethylene glycol 14 days @ 5 °C [1]

BLANKS: 2 to 10 field blanks per set

ACCURACY

RANGE STUDIED: see EVALUATION OF METHOD

BIAS: see EVALUATION OF METHOD

OVERALL PRECISION ($\hat{S}_{rT}$): not determined

ACCURACY: not determined

MEASUREMENT

TECHNIQUE: GAS CHROMATOGRAPHY, FID

ANALYTES: compounds above

DESORPTION: 2 mL methanol; ultrasonicate 30 min

INJECTION VOLUME: 1 µL

TEMPERATURE-INJECTION: 250 °C
-DETECTOR: 300 °C
-COLUMN: 40 °C, 8 °C/min to 230 °C

CARRIER GAS: He_2 @ 2.4 to 2.6 mL/min

COLUMN: Rtx-35 fused silica capillary, 30 m, 0.53-mm ID, 3-µm film

CALIBRATION: solutions of glycols in methanol

RANGE: 15 to 800 µg/sample

ESTIMATED LOD: see Table 2

PRECISION ($\bar{S}_r$): 0.04 to 0.09 [1]

APPLICABILITY: Under the GC parameters given in the method, the glycols listed above are baseline separated and can be identified based on retention time and quantified. Hexylene glycol can be determined by this method; however, no sampling or analytical evaluation has been conducted.

INTERFERENCES: No specific interferences were identified. The method yields baseline separation for all analytes.

OTHER METHODS: This method replaces NMAM 5500 [2], which was found deficient in the collection of ethylene glycol in aerosol form. Also ethylene glycol was not separated from propylene glycol by the chromatography.

REAGENTS:

1. Ethylene glycol, reagent grade.*
2. Propylene glycol, reagent grade.*
3. 1,3-Butylene glycol, reagent grade.*
4. Diethylene glycol, reagent grade.*
5. Triethylene glycol, reagent grade.*
6. Tetraethylene glycol, reagent grade.*
7. Methanol, chromatographic grade.*
8. Calibration stock solution, 10 mg/mL: Weigh aliquots of each glycol and dissolve in methanol.
9. Helium, purified.
10. Hydrogen, prepurified.
11. Air, filtered.

* See SPECIAL PRECAUTIONS

EQUIPMENT:

1. Sampler: XAD-7 OVS tube, 13-mm OD, containing two sections of XAD-7 (200 mg front/100 mg back section) separated by polyurethane foam plug. A glass fiber filter plug precedes the front section and a polyurethane foam plug follows the back section. Tubes are commercially available (SKC, Inc., #226-57).
2. Personal sampling pump, 0.5 to 2 mL/min, with flexible connecting tubing.
3. Gas chromatograph, flame ionization detector, integrator, and column (page 5523-1).
4. Ultrasonic bath.
5. Vials, autosampler, with PTFE-lined caps.
6. Vials, 4 mL, with screw caps.
7. Syringes, 10-µL and other sizes as needed, readable to 0.1 µL.
8. Flasks, volumetric, various sizes.
9. Pipets, various sizes.

SPECIAL PRECAUTIONS: Inhalation of glycol mists causes respiratory irritation, shortness of breath, and coughing. Methanol is flammable and a dangerous fire risk. Work with these compounds in a well-ventilated hood.

SAMPLING:

1. Calibrate each personal sampling pump with a representative sampler in line.
2. Remove front and rear caps from the tube immediately before sampling. Attach sampler to personal sampling pump with flexible tubing.
3. Sample at an accurately known flow rate between 0.5 and 2 L/min for a total sample size of 5 to 60 L.
4. Cap the samplers and pack securely in dry ice for shipment.

SAMPLE PREPARATION:

5. Place front sorbent section and glass fiber filter in a 4-mL screw cap vial. Place backup sorbent section in a separate vial. Discard foam plugs.
6. Add 2 mL of methanol to each vial and cap.
7. Place vials in an ultrasonic bath for 30 min to aid desorption.

CALIBRATION AND QUALITY CONTROL:

8. Calibrate daily with at least six working standards over the range of interest. Three standards (in duplicate) should cover the range from LOD to LOQ.
   a. Add known amounts of calibration stock solution to methanol in 10-mL volumetric flasks and dilute to the mark.
   b. Analyze together with samples and blanks (steps 11 and 12).
   c. Prepare calibration graph (peak area or height vs. µg glycol).
9. Determine desorption efficiency (DE) at least once for each lot of OVS tubes used for sampling in the calibration range (step 8).
   a. Prepare three samplers at each of six levels plus three media blanks.
   b. Inject a known amount of calibration stock solution directly onto the filter of OVS tubes. Draw air

through the sampler at 1 L/min for 60 min.
c. Cap the ends of the tubes and allow to stand overnight.
d. Desorb (steps 5 through 7) and analyze together with standards and blanks (steps 11 and 12).
e. Prepare a graph of DE vs. µg analyte recovered.

10. Analyze three quality control blind spikes and three analyst spikes to ensure that the calibration graph and DE graphs are in control.

MEASUREMENT:

11. Set gas chromatograph according to manufacturer's recommendations and to conditions given on page 5523-1. Inject 1-µL sample aliquot manually using solvent flush technique or with autosampler.
NOTE: If peak area is above the linear range of the working standards, dilute with methanol, reanalyze and apply the appropriate dilution factor in the calculations.
12. Measure peak areas.

CALCULATIONS:

13. Determine the mass, µg (corrected for DE), of each glycol found in the sample front (W_f) and back (W_b) sorbent sections, and in the average media blank front (B_f) and back (B_b) sorbent sections.
NOTE: If $W_b > W_f/10$, report breakthrough and possible sample loss.
14. Calculate concentration, C, of each analyte in the air volume sampled, V (L):

$$C = \frac{(W_f + W_b - B_f - B_b)}{V}, mg/m^3$$

EVALUATION OF METHOD:

The method was evaluated for six glycols (ethylene, propylene, 1,3-butylene, diethylene, triethylene, and tetraethylene). Desorption efficiency (DE) was determined by spiking known amounts of each glycol in methanol solution onto the glass fiber filter plug of the XAD-7 OVS tubes, drawing air through the spiked tubes at 1 L/min for 60 min, and analyzing. Recovery data along with LODs and LOQs for each analyte are listed in Table 2. When stored at 5°C, ethylene glycol samples on XAD-7 OVS tubes were stable for 14 days, and the other glycols were stable up to 28 days. Glycol aerosols were generated at three concentration levels (6 samples per concentration) from a ROSCO™ Model 1500 Fog Machine. Precision [as calculated from the pooled relative standard deviation ($\bar{S}_r$)] and mean bias for the glycols are as follows:

Analyte	Range Studied (µg/sample)	Precision ($\bar{S}_r$)	Bias
Ethylene glycol	33 to 218	0.043	-15%
Propylene glycol	26 to 187	0.062	-3.2%
1,3-butylene glycol	34 to 178	0.054	-0.5%
Diethylene glycol	68 to 219	0.047	-0.2%
Triethylene glycol	33 to 201	0.075	-4.0%
Tetraethylene glycol (2 levels)	32 to 197	0.035	+20%

The low recovery for ethylene glycol possibly may be attributed to increased volitility when sampled at 1 L/min [1]. Although hexylene glycol is separated by the chromatographic conditions given in the method, no evaluation of sampling or analytical parameters was done for this compound.

REFERENCES:

[1] Pendergrass, S.M. [1994]. Development of a sampling and analytical methodology for the

determination of glycols in air: Application to theatrical smokes. Unpublished paper presented at Pittsburgh Conference, Chicago, IL, March 1994.

[2] NIOSH [1984]. Ethylene glycol: Method 5500. In: Eller PM, Ed. NIOSH manual of analytical methods, 3rd ed. Cincinnati, OH: U.S. Department of Health and Human Services, HHS (NIOSH) Publication No. 84-100.

METHOD WRITTEN BY:

Stephanie M. Pendergrass, MRSB, DPSE

TABLE 1. GLYCOLS GENERAL INFORMATION

Analyte	Formula	MW	CAS #	RTECS #	Properties
Ethylene glycol	$C_2H_6O_2$	62.07	107-21-1	KW2975000	liquid; BP 197.2 °C; FP -13 °C; d 1.113 g/mL @ 20 °C; n_D 1.4310; vp 0.007 kPa (0.05 mm Hg) @ 20°C; explosive limits 3.2 to 15.3% v/v in air
Propylene glycol	$C_3H_8O_2$	76.10	57-55-6	TY2000000	liquid; BP 188 °C; FP -60 °C ; d 1.038 g/mL @ 20 °C; n_D 1.4320; vp 0.009 kPa (0.07 mm Hg) @ 20°C; explosive limits 2.6 to 12.5% v/v in air
1,3-Butylene glycol	$C_4H_{10}O_2$	90.12	107-88-0	EK0440000	liquid; BP 207.5 °C; d 1.0059 g/mL @ 20 °C; n_D 1.4400; vp 0.06 mm Hg @ 20 °C
Diethylene glycol	$C_4H_{10}O_3$	106.12	111-46-6	ID5950000	liquid; BP 245 °C; FP -6.5 °C; d 1.118 g/mL @ 20 °C; n_D 1.4460 @ 25 °C; vp <0.01 mm Hg @ 20°C; explosive limits 3 to 7% v/v in air
Triethylene glycol	$C_6H_{14}O_4$	150.17	112-27-6	YE4550000	liquid; BP 285 °C; FP -5 °C; d 1.125 g/mL @ 20 °C; n_D 1.4550; vp <0.001 mm Hg @ 20 °C; explosive limits 0.9 to 9.2% v/v in air
Tetraethylene glycol	$C_8H_{18}O_5$	194.23	112-60-7	XC2100000	liquid; BP 327.3 °C; FP -4 °C; d 1.125 g/mL @ 20 °C; n_D 1.4577; vp >0.001 mm Hg @ 20 °C

TABLE 2. GLYCOL RECOVERY DATA

Analyte	LOD (µg/sample)	LOQ (µg/sample)	Desorption Efficiency Spikes[a]		$\bar{S}_r$[b]
			100 µg (% Recovery)	200 µg (% Recovery)	
Ethylene glycol	7	22	93.4	101	0.059
Propylene glycol	6	13	83.4	92.5	0.064
1,3-Butylene glycol	6	12	98.8	102	0.072
Diethylene glycol	16	48	94.6	114	0.041
Triethylene glycol	14	42	85.3	98.7	0.043
Tetraethylene glycol	14	42	111	141	0.092

[a] n = 6 for each spiking level
[b] Pooled Relative Standard Deviation

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August 3, 1998

Lorri White
Environmental Connections
P.O. Box 4704
Chapel Hill, NC 27515

Re: Glycol Analysis Project

Dear Lorri,

I would like to summarize for you the results of the validation portion of the glycol project. As you know we were contracted to perform a limited validation for the recovery of four glycol compounds sampled on ORBO special sampling tubes. We studied linearity, accuracy (recovery), and reproducibility for propylene glycol, butylene glycol, diethylene glycol, and triethylene glycol. We were not able to obtain acceptable recoveries when concentrating methanol extracts for the four glycol products. however. the chromatography and linearity supported the calculation of results down to the 4.0 µg/sample level.

Initial chromatography was completed by preparing solutions of the four glycol compounds separately in methanol. Once the chromatographic order was established, a mixed standard of all four compounds was used in further experimentation. The mixed calibration standards were prepared by serially diluting a 1000 µg/mL solution of all four compounds at levels of 500. 200, 40.0, 8.0, and 2.0 µg/mL. The calibration curves were computed using Hewlett-Packard Chemstation software and hardcopy printouts are enclosed.

Spiked tube recovery and precision were examined as follows. Using the 1000 µg/mL mixed standard solution, a series of tubes were spiked at levels of 4.0, 20, 50, 100, and 200 µg per tube. A minimum of 1 liter of air was drawn through each tube. The tubes were then desorbed (by sonication) with 2.0 mLs of reagent grade methanol. The extracts were then taken for gas chromatographic analysis. The results of the study are found on the enclosed "Glycol Spike Recovery" worksheet.

Samples tubes were prepared in the same manner as those in the spike recovery section of the validation. An example sample chromatogram is enclosed. The results of sample analyses are not corrected for desorption efficiency (recovery) and are not corrected for any glycol amount present in blank samples.

Thank you for choosing LabCorp Analytics Laboratory for your testing needs.

Sincerely,

James E. Maguire

enc.

Environmental Connections
Glycol Project Recovery Worksheet

Glycol Spike Recovery

	Propylene Glycol	Butylene Glycol	Diethylene Glycol	Triethylene Glycol
4 µg spike	3.82	3.76	4.28	4.22
4 µg spike	2.94	2.86	4.86	4.20
% Recovery	**84.5%**	**82.8%**	**116.6%**	**105.3%**
$ RSD	18.4%	19.2%	10.4%	0.3%
20 µg spike	14.13	14.43	*	15.1
20 µg spike	15.39	16.18	*	17.56
20 µg spike	15.29	15.87	*	14.96
% Recovery	**74.7%**	**77.5%**		**79.4%**
$ RSD	4.7%	6.0%		9.2%
50 µg spike	40.05	43.76	*	45.18
50 µg spike	40.32	43.28	*	44.05
50 µg spike	42.36	43.72	*	42.52
% Recovery	**81.8%**	**87.2%**		**87.8%**
$ RSD	3.1%	0.6%		3.0%
100 µg spike	86.15	92.13	*	91.56
100 µg spike	89.82	95.17	*	97.93
100 µg spike	86.47	91.39	*	89.85
% Recovery	**87.5%**	**92.9%**		**93.1%**
$ RSD	2.3%	2.2%		4.6%
200 µg spike	181.4	192.0	*	209.8
200 µg spike	181.0	190.7	*	208.1
200 µg spike	181.0	190.9	*	204.0
% Recovery	**90.6%**	**95.6%**		**103.7%**
$ RSD	0.1%	0.4%		1.4%

* No data available.

Work performed July 9 through July 29, 1998 by J.A Calpin and J.E. Maguire

C_nH_{2n+2} where $n \geq 16$ MW: not pertinent CAS: 8012-95-1 RTECS: PY8030000

METHOD: 5026, Issue 2 **EVALUATION: FULL** **Issue 1: 15 August 1987**
Issue 2: 15 August 1994

OSHA : 5 mg/m³
NIOSH: 5 mg/m³; STEL 10 mg/m³
ACGIH: 5 mg/m³ (as sampled by a method which does not collect vapor)

PROPERTIES: liquid; d 0.8 to 0.9 g/mL @ 20 °C; BP 360 °C; vapor pressure negligible

SYNONYMS: airborne mist of white mineral oil or the following water-insoluble petroleum-based cutting oils: cable oil; cutting oil; drawing oil; engine oil; heat-treating oils; hydraulic oils; machine oil; transformer oil.

SAMPLING

SAMPLER: MEMBRANE FILTER (37-mm diameter, 0.8- or 5-µm pore size, PVC or MCE)

FLOW RATE: 1 to 3 L/min

VOL-MIN: 20 L @ 5 mg/m³
-MAX: 500 L

SHIPMENT: routine

SAMPLE STABILITY: stable

BLANKS: 2 to 10 field blanks per set

BULK SAMPLE: required for quantitative data

ACCURACY

RANGE STUDIED: 2.5 to 11.7 mg/m³ [1] (100-L samples)

BIAS: - 0.84% [1,2]

OVERALL PRECISION ($\hat{S}_{rT}$): 0.065 [1]

ACCURACY: ± 11.8%

MEASUREMENT

TECHNIQUE: INFRARED SPECTROPHOTOMETRY

ANALYTE: mineral oil

EXTRACTION: 10 mL $C_2Cl_3F_3$ (Freon 113)

IR SCAN: 3200 to 2700 cm^{-1} vs. blank $C_2Cl_3F_3$

CALIBRATION: standard solutions of mineral oil in $C_2Cl_3F_3$

RANGE: 0.1 to 2.5 mg per sample

ESTIMATED LOD: 0.05 mg per sample [3]

PRECISION ($\hat{S}_r$): 0.05 [3]

APPLICABILITY: The working range is 1 to 20 mg/m³ for a 100-L air sample. This method is applicable to all trichlorotrifluoroethane-soluble mineral oil mists, but not to (nor does OSHA's standard cover) semi-synthetic or synthetic cutting fluids.

INTERFERENCES: Any aerosol (e.g., tobacco smoke) which absorbs infrared radiation near 2950 cm-1 interferes.

OTHER METHODS: This revises P&CAM 283 [3]. P&CAM 159 [4] and S272 [5] use similar samplers with measurement by fluorescence spectrophotometry. These methods have not been revised because of limited applicability (i.e., not all mineral oils contain fluorescent components and other fluorescent compounds interfere). Infrared analysis overcomes both of these limitations.

REAGENTS:

1. Trichlorotrifluoroethane ($C_2Cl_3F_3$).
2. Stock mineral oil standard, 20 mg/mL. Weigh 1.0 g of the bulk mineral oil sample into a 50-mL volumetric flask. Dilute to volume with $C_2Cl_3F_3$. Prepare in duplicate.

* See SPECIAL PRECAUTIONS.

EQUIPMENT:

1. Sampler: membrane filter, PVC or MCE, 37-mm, 0.8- or 5-µm pore size; two-piece filter cassette.
   NOTE 1: High concentrations of oil mist may plug membrane filters. Glass fiber filters have a higher capacity for oil mist than membrane filters.
   NOTE 2: Handle filters carefully with tweezers to avoid contamination by skin oil.
2. Personal sampling pump, 1 to 3 L/min, with flexible connecting tubing.
3. Infrared spectrophotometer, double beam, dispersive, with scanning capability in the 3200-2700 cm^{-1} region, and two 10-mm spectrophotometer cells, infrared quartz with PTFE stoppers mounted in demountable cell holders.
   NOTE: Standard glass cells may be used if infrared quartz cells are not available.
4. Vials, scintillation, 20-mL, with foil-lined or PTFE-lined caps.*
5. Volumetric flasks, 10-, 25-, and 50-mL.*
6. Volumetric pipet or reagent dispenser, 10-mL.*
7. Pipets, 2- to 250-µL.
8. Tweezers.

* Rinse glassware with $C_2Cl_3F_3$. Air dry.

SPECIAL PRECAUTIONS: None.

SAMPLING:

1. Calibrate each personal sampling pump with a representative sampler in line.
2. Sample at an accurately known flow rate in the range 1 to 3 L/min for a total sample size of 20 to 500 L.
   NOTE: High concentrations of oil mist may plug membrane filters creating unacceptably high pressure drops. If this occurs, terminate sampling.
3. Collect 5 to 10 mL of unused, undiluted mineral oil in a vial. Submit with samples for standard preparation.

SAMPLE PREPARATION:

4. Using tweezers, transfer each sample or blank filter to a vial. Add 10.0 mL $C_2Cl_3F_3$. Cap and shake vigorously.

CALIBRATION AND QUALITY CONTROL:

5. Calibrate daily with at least six working standards.
   a. Add known amounts of stock mineral oil standard to $C_2Cl_3F_3$ in 10-mL volumetric flasks and dilute to the mark to obtain mineral oil concentrations in the range 5 to 250 µg/mL.
   b. Analyze with samples and blanks (step 8).
   c. Prepare calibration graph (peak absorbance vs. mg mineral oil).
6. Determine recovery (R) at least once for each lot of filters used for sampling in the range of interest. Prepare three filters at each of five levels plus three media blanks.

a. Deposit a known amount of stock mineral oil standard onto the filter. Allow solvent to evaporate.
b. Store samples overnight in filter cassettes.
c. Prepare and analyze with working standards.
d. Prepare a graph of R vs. µg mineral oil recovered.

7. Analyze three quality control blind spikes and three analyst spikes to ensure that the calibration graph and R graph are in control.

MEASUREMENT:

8. Scan each standard solution and each blank or sample filter extract from 3200 to 2700 cm^{-1} in absorbance mode vs. $C_2Cl_3F_3$ in reference beam. Record absorbance at wavelength of largest absorbance near 2940 cm^{-1} (± 11.8%).

CALCULATIONS:

9. Determine the mass, µg (corrected for R), of mineral oil found in the sample (W) and in the average media blank (B) from the calibration graph.
10. Calculate concentration, C, of mineral oil in the air volume sampled, V (L):

$$C = \frac{(W - B)}{V}, \text{ mg/m}^3.$$

EVALUATION OF METHOD:

The sampling portion of this method was evaluated over the range 2.5 to 11.7 mg/m^3 at 22 °C and 755 mm Hg using 100-L air samples of Gulf machine cutting oil with measurement by fluorescence spectrophotometry. Mixed cellulose ester filters, 0.8-µm pore size, were used for sampling [1,5]. The overall precision was 0.065 with an average recovery of 98%. The infrared measurement method was subsequently evaluated by NIOSH [2,3]. Precision and accuracy of the infrared and fluorescence spectrophotometric techniques are similar.

REFERENCES:

[1] Documentation of the NIOSH Validation Tests, S272, U.S. Department of Health, Education, and Welfare, Publ. (NIOSH) 77-185 (1977), available as PB 274-248 from NTIS, Springfield, VA 22161.
[2] Bolyard, M. L. Infrared Quantitation of Mineral Oil Mist in Personal Air Samples, AIH Conference, Houston, TX (1980).
[3] NIOSH Manual of Analytical Methods, 2nd ed., Vol. 4, P&CAM 283, U.S. Department of Health, Education, and Welfare, Publ. (NIOSH) 78-175 (1978).
[4] Ibid., Vol. 1, P&CAM 159, U.S. Department of Health, Education, and Welfare, Publ. (NIOSH) 77-157-A (1977).
[5] Ibid., Vol. 3, S272, U.S. Department of Health, Education, and Welfare, Publ. (NIOSH) 77-157-C (1977).

METHOD REVISED BY:

Charles Lorberau, NIOSH/DPSE.

APPENDIX B

Data Collection Forms

PUMP CALIBRATION

Date	Pump ID	Start Time	Start Flow Rate	End Time	End Flow Rate	Average Flow Rate

Notes:

SMOKE AND HAZE EQUIPMENT/PDR CALIBRATION

Machine:

Machine Setting:

Fluid:

Bulk Sample ID:

Date:

Time	PDR ID	PDR Reading	Pump ID	Sample ID	Sample Duration

Notes:

SMOKE AND HAZE EQUIPMENT MONITORING

Machine:

Fluid:

Date:

Time	PDR ID	PDR Reading	PDR Location	Machine Setting	Sample Duration

Notes: