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**ACTORS' EQUITY ASSOCIATION/THE  
LEAGUE OF AMERICAN THEATRES  
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**SUMMARY**

In July and August 1990, the National Institute for Occupational Safety and Health (NIOSH) received requests from the Actors' Equity Association (AEA) and the League of American Theatres and Producers, Inc. (LATP) to investigate possible health effects associated with the use of theatrical "smoke" in Broadway productions. In 1991, NIOSH representatives conducted site visits, summarized in the revised interim report provided as an appendix to this report. In 1993, NIOSH investigators conducted a follow-up investigation to further characterize "smoke" exposures and to determine whether there were measurable respiratory effects among performers.

**INITIAL SURVEY: JUNE 17 AND JULY 2, 1991**

Four Broadway productions (*Les Miserables*, *Miss Saigon*, *Phantom of the Opera*, and *Grand Hotel*) using theatrical "smoke" were selected for study. Dress rehearsals were arranged to conduct personal breathing-zone (PBZ) and general area (GA) air sampling to quantitate the "smoke" exposure. A questionnaire was administered to the actors; it addressed the frequency and severity of irritant and respiratory symptoms associated with exposure to theatrical "smoke". A small number of PBZ air samples were collected on electricians, carpenters, and other personnel who may have been exposed to the theatrical "smoke" during a performance. To determine if the prevalence of symptoms among actors in shows using theatrical "smoke(s)" differed from the symptom prevalence in non-"smoke"-using productions, NIOSH investigators administered the same questionnaire to performers in five Broadway productions in which no theatrical "smoke" was used (*Lost in Yonkers*, *Gypsy*, *Getting Married*, *Once on This Island*, and *Six Degrees of Separation*).

Although theatrical "smoke" was visibly evident during all of the "smoke" performances, concentrations of potential airborne contaminants from all of the PBZ and GA air samples were very low when compared to applicable Occupational Safety and Health Administration (OSHA) Permissible Exposure Limits (PELs), American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Values (TLVs), or NIOSH Recommended Exposure Limits (RELs). For example, acrolein and acetaldehyde, suspected to be possible decomposition products from the heating of the glycol-based fog fluids, were not found in any of the PBZ or GA air samples. None of the PBZ air samples had detectable amounts of formaldehyde.

Although 120 PBZ and GA air samples were collected for glycols (specifically ethylene, propylene, 1,3-butylene, diethylene, and triethylene glycols) during this investigation, NIOSH chemists subsequently determined that NIOSH Sampling and Analytical Method No.5500 developed for ethylene glycol was inadequate to identify and quantitate other glycols. In at least one instance, ethylene glycol was incorrectly identified in an air sample. Since it was possible that interferences from other glycol analytes could have occurred, quantitative results could not be reported. Qualitatively, glycols were present in some of the PBZ and GA samples collected in all four theatrical productions in which sampling was conducted.

Air samples (both PBZ and GA) were collected for mineral oil mist during a dress rehearsal of *Miss Saigon*. Concentrations ranged up to 1.35 milligrams per cubic meter (mg/m<sup>3</sup>), time-weighted average (TW A) over the duration of the play. The highest levels were measured in GA samples positioned on stage. All of the measured concentrations were well below the OSHA, NIOSH, and ACGIH exposure criteria of 5 mg/m<sup>3</sup> for up to a full-shift (8 to 10 hours) TW A exposure.

All 224 actors from nine Broadway productions completed questionnaires. Of this group, 134 questionnaires (60%) were from actors appearing in the four productions using theatrical "smoke," and 90 questionnaires (40%) were from actors appearing in the five control productions. When compared to actors from the non-"smoke" productions, actors from two or more of the four productions utilizing theatrical "smoke" reported experiencing a significantly greater prevalence of nasal symptoms (sneezing, runny or stuffy nose), respiratory symptoms (cough, wheeze, breathlessness, chest tightness), and mucous membrane symptoms (sore throat, hoarseness, dry throat, itchy/burning eyes, dry eyes) during their performances for the week prior to the survey.

#### FOLLOW-UP SURVEY: NOVEMBER 18 - DECEMBER 4, 1993

The medical portion of this follow-up was conducted in two phases and designed to evaluate the relationship between acute changes in the lung function and "smoke" exposure status among performers reporting symptoms consistent with occupational asthma. In the first phase of the evaluation, NIOSH investigators administered a screening questionnaire to all performers in three "smoke" productions (*Les Miserables*, *Miss Saigon*, and *Phantom of the Opera*) and three non-"smoke" productions (*Any Given Day*, *She Loves Me*, and *The Sisters Rosenzweig*). The purpose of the screening questionnaire was to identify performers with symptoms suggestive of occupational asthma. All symptomatic performers, and a random sample of non-symptomatic performers, were invited to participate in the follow-up case-control study (Phase II).

The environmental evaluation consisted of GA air samples collected during live performances of *Les Miserables*, *Miss Saigon*, and *Phantom of the Opera*. Since special dress rehearsals could not be arranged, no PBZ air sampling was conducted. Air samples were collected for glycols, aldehydes (formaldehyde and acrolein), mineral oil mist (*Miss Saigon*), and volatile organic compounds.

Thirty-seven symptomatic and 68 non-symptomatic performers made up the Phase II study population of 105 performers. All participants were asked to complete a self-administered questionnaire addressing medical and work history. Participants were also asked to perform,

after verbal instruction, serial determinations of their peak expiratory flow rate (PEFR) using portable flow meters. Of the 105 participants, 65 (62%) submitted at least a partial questionnaire or PEFR information. Five persons met the case definition for theatrical work-related occupational asthma. Three of these five were exposed to theatrical "smoke" during the study and two were not. Of the 60 persons who did not meet the case definition, 16 had been identified as being "symptomatic" in the Phase I portion of the evaluation, and were therefore excluded from further analysis. This left 45 non-case performers; 27 of these were "smoke"-exposed and 18 were not. The odds ratio (OR) for the association between being a case and being "smoke"-exposed was 1.0 (95% confidence interval [CI] = 0.1-13.1).

This indicates that performers with asthma-like symptoms and abnormal peak-flow meter results ("cases") were not more likely to have been exposed to theatrical "smoke" when compared to persons who did not meet this case definition.

Analysis of the bulk samples revealed the expected glycols, based on information provided by the manufacturers. Two of the three samples contained propylene glycol, 1,3-butylene glycol, and triethylene glycol as the major components. The remaining bulk sample contained ethylene glycol and diethylene glycol as the major components, with trace amounts of triethylene glycol and propylene glycol.

Ethylene glycol was sampled in two of the three productions (*Phantom of the Opera* and *Miss Saigon*) at concentrations of 0.4 mg/m<sup>3</sup> or less, well below the OSHA PEL of 127 mg/m<sup>3</sup>. Propylene glycol was detected in samples from all three productions, ranging from <0.01 to 1.9 mg/m<sup>3</sup>. Triethylene glycol and 1,3-butylene glycol were detected only in *Les Miserables*, ranging from <0.04 to 3.7 mg/m<sup>3</sup> and 0.16 to 2.1 mg/m<sup>3</sup>, respectively. Formaldehyde concentrations, using NIOSH Sampling and Analytical Method 3500 (sodium bisulfite-filled impingers), ranged from <0.002 to 0.04 parts per million (ppm), well below the OSHA and ACGIH exposure criteria. These formaldehyde concentrations are typical of those which NIOSH investigators have measured in non-industrial work places. Acrolein was not detected on any of the GA samples (Minimum Detectable Concentration [MAC] = 0.016 mg/m<sup>3</sup>). Oil mist concentrations were below 0.13 mg/m<sup>3</sup>, far below NIOSH, OSHA, and ACGIH exposure criteria of 5.0 mg/m<sup>3</sup> (TWA). The thermal desorption analysis revealed that only two samples (from *Phantom of the Opera*) contained even modest concentrations; levels of compounds detected on all other samples were very low. Major compounds detected were mostly C9-C12 aliphatic hydrocarbons and C9H12 alkyl benzenes (trimethyl benzenes, propyl benzenes, etc.). Other compounds identified on these included 1,1,1-trichloroethane, acetaldehyde, acetone, isopropanol, toluene, limonene, siloxanes, and perchloroethylene.

**Based on the results of this study, there is no evidence that theatrical "smoke," at the levels found in the theaters studied, is a cause of occupational asthma among performers.**

Some of the constituents of theatrical "smoke," such as the aerolized glycols and mineral oil, could have irritative or mucous membrane drying properties in some individuals. Therefore, it is reasonable to minimize exposures by such means as relocating "smoke" machines to avoid exposing actors to the direct, concentrated release of the aerosols, minimizing the amount of "smoke" necessary for the production, and using only fog fluids approved by the manufacturers of the machines. The glycols used should be at the level of "food grade" or "high grade." Glycol-based systems should also be designed to

heat the fog fluids only to the lowest temperature needed that achieve proper aerosolization. This would help to avoid overheating the fluid and minimize the generation of decomposition products.

Keywords: SIC 7922 (Theatrical Producers and Miscellaneous Theatrical Services), ethylene glycol, propylene glycol, 1,3-butylene glycol, triethylene glycol, oil mist, fog, aldehydes, formaldehyde, respiratory , irritation, pulmonary function test, questionnaire, actors.

## SUMMARY

In July and August, 1990 the National Institute for Occupational Safety and Health (NIOSH) received requests from the Actors' Equity Association (AEA) and the League of American Theatres and Producers, Inc. to investigate possible health effects associated with the use of theatrical "smokes" in Broadway productions.

Four Broadway productions (*LES MISERABLES*, *MISS SAIGON*, *PHANTOM OF THE OPERA*, AND *GRAND HOTEL*) which used theatrical smoke were selected and dress rehearsals were arranged to conduct personal breathing-zone (PBZ) and general area (GA) air sampling and to administer a questionnaire to the actors detailing the frequency and severity of irritant and respiratory symptoms (if any) when exposed to theatrical smoke. A small number of PBZ air samples were collected on electricians, carpenters, and other personnel who may have been exposed to the theatrical smoke during a performance. To determine if the prevalence of symptoms among actors in shows using theatrical smoke(s) differed from the symptom prevalence in non-smoke productions, NIOSH investigators also administered the same questionnaire to actors in five Broadway productions in which no theatrical smoke was used (*LOST IN YONKERS*, *GYPSY*, *GETTING MARRIED*, *ONCE ON THIS ISLAND*, AND *SIX DEGREES OF SEPARATION*). The actors in these non-smoke productions are termed "controls" in this report.

Air sampling at the smoke productions was completed during dress rehearsals held between June 17 and July 2, 1991. Questionnaires were administered during this same time period to all of the selected Broadway productions. Although theatrical smoke was visibly evident during all of the performances, results from all of the PBZ and GA air samples collected were very low when compared to applicable Occupational Safety and Health Administration (OSHA) Permissible Exposure Limits (PELs), American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Values (TLVs), or NIOSH Recommended Exposure Limits (RELs). For example, acrolein and acetaldehyde, suspected to be possible decomposition products from the heating of the glycol-based fog fluids, were not found on any of the PBZ or GA air samples collected during this survey. None of the PBZ air samples had detectable amounts of formaldehyde.

*NIOSH Sampling and Analytical Method No.5500 was developed for ethylene glycol alone. NIOSH investigators have recently determined that this method may have deficiencies when used to identify and quantitate other similar glycols as were encountered in this evaluation (such as propylene, butylene, diethylene, and triethylene glycols). In at least one instance ethylene glycol was incorrectly identified in an air sample. Since it is possible that interferences from other glycol analytes may have occurred, only qualitative glycol sampling data will be discussed in the final report. The sections of this revised interim report affected by these analytical problems have been highlighted. A thorough discussion of the analytical problems encountered while using NIOSH Sampling and Analytical Method 5500 for these glycols will be contained in the final report.*

Only 21 of the 120 PBZ and GA air samples collected for glycols (specifically ethylene, propylene, 1,3 butylene, diethylene, and triethylene glycols) during this investigation had detectable amounts of these substances. Excluding the results obtained from two GA air samples situated directly adjacent to the on-stage smoke machines used in LES MISERABLES, all of the remaining glycol concentrations were extremely low, ranging up to 2.1 milligrams per cubic meter (mg/m<sup>3</sup>). These concentrations were well below the OSHA PEL for ethylene glycol of 127 mg/m<sup>3</sup> (short-term exposure limit of 15 minutes). There is no NIOSH REL for ethylene glycol; however, because of the potential teratogenicity and the known respiratory irritation at the level chosen for the OSHA PEL, NIOSH has suggested that the current OSHA PEL be revised. There are no OSHA, NIOSH, or ACGIH exposure criteria for the other glycols.

Air samples (both PBZ and GA) were collected for mineral oil mist during a dress rehearsal of *MISS SAIGON*. Concentrations ranged up to 1.35 mg/m<sup>3</sup>, TWA over duration of the play. The highest levels were measured in GA samples positioned on stage. All of the measured concentrations were well below the OSHA, NIOSH, and ACGIH exposure limits of 5 mg/m<sup>3</sup> for up to a full-shift (8 to 10 hours) TWA exposure.

All 224 actors from nine Broadway productions completed questionnaires. Of this group, 134 questionnaires (60%) were from actors appearing in the four productions using theatrical smokes, and 90 questionnaires (40%) were from actors appearing in the five control productions.

When compared to actors from the non-smoke productions, actors from two or more of the four productions utilizing theatrical smoke reported experiencing significantly greater prevalence of nasal symptoms (sneezing, runny or stuffy nose), respiratory symptoms (cough, wheeze, breathlessness, chest tightness), and mucous membrane symptoms (sore throat, hoarseness, dry throat, itchy, burning eyes, dry eyes) during their performances for the week prior to the survey. Although some of the constituents of theatrical smoke (primarily the glycols) have irritative properties, the reason for the high symptom prevalence in the productions that use theatrical smoke is not clear, since the time-weighted average concentrations of the glycols measured during the performances were quite low. It is possible however, that the smoke concentrations could be sufficiently high during the short periods of time that the smoke is generated to contribute to the symptoms reported by the actors.

*NIOSH Sampling and Analytical Method No.5500 was developed for ethylene glycol alone. NIOSH investigators have recently determined that this method may **have deficiencies** when used to identify and quantitate other similar glycols as were encountered in this evaluation (such as propylene, butylene, diethylene, and triethylene glycols). In at least one instance ethylene glycol was incorrectly identified in an air sample. Since it is possible that interferences from other glycol analytes may have occurred, only **qualitative** glycol sampling data will be discussed in the final report. The sections of this revised interim report affected by these analytical problems have been highlighted. A thorough discussion of the analytical problems encountered while using NIOSH Sampling and Analytical Method 5500 for these glycols will be contained in the final report.*

While some mucous membrane irritative symptoms (eyes, nose, throat) might be expected, the high prevalence of work related lower respiratory symptoms (cough, wheeze, chest tightness, and shortness of breath) reported by the smoke-exposed actors was surprising. It is possible that the questionnaire was too sensitive in its design and caused an over-reporting of symptoms, the constituents of theatrical smoke may be more irritative at low concentrations than previously documented, or there may be other factors involved. Since the etiology is unclear at this time, a return visit is planned to gather further information on the nature of these symptoms.

In this interim period, the NIOSH investigators recommend that only smoke fluids which are approved by the manufacturers be used. For the glycols which are used, their purity should be at the level of "food grade" or "high grade" to minimize the presence of impurities. Relocating the smoke machine(s) (either glycol or mineral oil-based) to avoid exposing actors to the direct, concentrated release of the aerosols may be advantageous in reducing complaints. Additionally, reducing the amount of theatrical smoke to the minimum necessary is also advisable.

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