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REPORT OF FINDINGS

**RECOMMENDED EXPOSURE GUIDELINES
FOR GLYCOL FOGGING AGENTS**

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REPORT OF FINDINGS

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INTRODUCTION AND SUMMARY OF FINDINGS

Pursuant to an award to conduct research on glycol fogging agents on behalf of Entertainment Services and Technology Association, The Cohen Group has reviewed available information pertaining to both the use of six glycols as fogging agents in theatrical productions and the effects of exposure to said agents. The purpose of the review was to establish, where feasible, safe airborne concentrations for the six fogging agents under the conditions of use present during theatrical productions. The glycols of interest are:

- Triethylene glycol
- Diethylene glycol
- Monopropylene glycol (propylene glycol; 1,2-propanediol)
- Dipropylene glycol
- Glycerin (glycerol; 1,2,3-propanediol)
- Butylene glycols (1,2-, 1,3-, 2,3-, and 1,4-butanediols)

[Please note that glycerin is a trihydric alcohol and not a glycol (i.e., a dihydric alcohol). However, to facilitate presentation of the information in this report, all six of the above-listed compounds are referred to as glycols. Physically and chemically, glycerin is very similar to the glycol family of chemicals.]

Our review of available information has led us to recommend, pending further investigation, the following levels as “interim” or “working” limits. The concentrations are believed to represent average airborne concentrations to which nearly all healthy individuals may be exposed without adverse health effects, either in the short term or long term. The concentrations are also believed to be readily achievable in theatrical productions without compromising the intended aesthetic goal.

Glycol	Recommended Limit
Triethylene glycol	10 mg/m ³
Diethylene glycol	10 mg/m ³
Monopropylene glycol	10 mg/m ³
Dipropylene glycol	10 mg/m ³
Glycerin	10 mg/m ³
1,2- and 1,3-Butanediols	10 mg/m ³
1,4-Butanediol	1 mg/m ³
2,3-Butanediol	5 mg/m ³

All recommended limits are proposed as 8-hour time-weighted averages for the chemical in either the vapor or aerosol state. The abbreviation "mg/m³" denotes milligrams of the chemical per cubic meter of air.

LIMITATIONS

The Cohen Group has prepared this report for the exclusive use of ESTA for this particular project. The work was performed within the limitations set forth in the Agreement as to the degree of care, amount of time and expense, and any other limitations contained in the Agreement. No other representation, warranty or guarantee, expressed or implied, is included or intended in this report.

METHODOLOGY

The conclusions and recommendations presented in this report are based upon information obtained through document review (i.e., reference texts, journal articles, research and investigation reports, and correspondence), and telephone interviews. A literature search employing CAS numbers, chemical names, and other relevant keywords was performed utilizing Medline, Hazardous Substances Data Bank, and Registry of Toxic Effects of Chemical Substances. The documents reviewed are listed in Attachment A.

FINDINGS

This section of the report discusses the information that was considered in order to develop recommended exposure limits.

THE CHARACTERISTICS OF GLYCOL-BASED THEATRICAL FOGS

Fogging machines generate a fog by introducing a water/glycol mixture to a heating element, then forcing the ensuing fog through a delivery port or nozzle into the local environment. The heating element may be either a coiled copper tube or a metal heating block. The element is heated to temperatures specified by the manufacturer, typically in the range of 218° to 370° C (425° to 700° F). The heated solution becomes airborne as a vapor and is then expelled from the nozzle of the unit, cooling into a finely-divided, opaque aerosol. The amount of fog released is controlled by the machine operator in order to achieve the desired density on stage.

Reportedly, the fog may also be generated ultrasonically, but the documents we reviewed did not address use of ultrasonic foggers.

EXPOSURES TO GLYCOL FOGGING AGENTS DURING THEATRICAL PRODUCTIONS

The National Institute for Occupational Safety and Health (NIOSH) has conducted several investigations into the use of fogging agents in theatrical productions. Two of the investigations, conducted in 1991 and 1993, evaluated Broadway productions and included air monitoring either during rehearsals or performances. The 1991 investigation was conducted in response to performers' concern regarding health effects potentially associated with exposure to fogs ("smoke"). Although 120 air samples were collected in the 1991 investigation, subsequently, in Report No. 90-0355-2499, NIOSH stated that the data for airborne glycol concentrations developed in their 1991 study (HETA 90-355) should be regarded as qualitative, not quantitative, due to deficiencies in the sampling and analytical methodology employed in 1991. NIOSH developed and employed new methodology for the 1993 study.

The 1993 NIOSH study (90-0355-2499) evaluated exposure through collection of area samples during productions of *Les Miserables*, *Miss Saigon*, and *Phantom of the Opera*. Samples were collected on or near the stage. Sampling times generally exceeded the length of the plays by up to an hour. In 1991, the foggers used in the same three productions were identified as NuHaze, Aqua Fog, and Rosco; similar information was not provided with the 1993 study. The glycols used in the foggers in the 1993 study were identified as ethylene glycol, propylene glycol, 1,3-butylene glycol, diethylene glycol, and/or triethylene glycol. Propylene glycol was detected in air samples collected at each of the three productions, with concentrations ranging from less than 0.01 to 1.9 mg/m³. Triethylene glycol and 1,3-butylene glycol were detected only at one of the three productions, at concentrations ranging from less than 0.04 to 3.7 mg/m³ and 0.16 to 2.1 mg/m³, respectively.

In 1993, NIOSH investigators teamed with Lightwave Research/High End Systems, Inc. to evaluate airborne levels of glycols, aldehydes and volatile organic compounds. A Lightwave Research F-100 fog generator was used to provide a fog to an unventilated test room. Two fogging solutions were used, one comprised of triethylene glycol and water and another which was a mixture of propylene glycol, triethylene glycol and water. The former solution was used to simulate "normal" theatrical uses of a fog and the latter was used to generate both normal and "heavy" fogs. The heavy fog was regarded as "atypical since theatrical lights, lasers, and other special effects were muted," although "objects and people were visible at approximately 30 feet." During normal fog conditions, propylene glycol concentrations were found to range from 1.7 to 2.9 mg/m³ and triethylene glycol concentrations were found to range from 2.7 to 4.8 mg/m³. During heavy fog conditions, propylene glycol concentrations were found to range from 7.6 to 9.6 mg/m³, while triethylene glycol concentrations were found to range from 18.8 to 24.2 mg/m³.

A 1993 study performed by the British organization NOSH for J.E.M. Smoke Machines Limited, entitled "Report on Investigation into Health and Safety Aspects of Smoke Generator Machines," evaluated airborne concentrations of propylene glycol and triethylene glycol in test rooms. The

fogging units' heating element temperature was 270°C. Two densities of fogs were generated: low-density and high-density. The two conditions were defined qualitatively, with low-density fog described as typical of that found in "a disco, theatre or other similar recreational venue." The high-density condition was described as typical of "theatrical usage purposes" where a "hand in front of the face at arms length was just visible." The investigators found propylene glycol concentrations to be less than 1.5 mg/m³ and triethylene glycol concentrations to be less than mg/m³ in low density room (i.e., neither were detected). In high-density conditions, propylene glycol concentrations were found to be range from 1.7 to 6.4 mg/m³ and triethylene glycol concentrations to be less than 3 mg/m³.

THE TOXICOLOGY OF THE GLYCOLS OF INTEREST

Prolonged and repeated inhalation of triethylene glycol and propylene glycol concentrations well above those present in high-density fog theatrical productions has been repeatedly demonstrated to not pose a health hazard to human subjects. Both glycols have generally been found to be not irritating to the eyes and skin, although splashing the pure compound into the eye may produce transient irritation. However, even though propylene glycol is widely used in topically applied cosmetics and pharmaceuticals, it is known to produce allergic skin reactions and/or primary irritation in unusually sensitive individuals.

A 1992 Union Carbide study found that prolonged exposure to very high concentrations of triethylene glycol (i.e., 4 days at 5000 mg/m³) would kill rats, but prolonged exposure to 500 and 2000 mg/m³ had no toxic effect on rats other than drying of the eyes, nose and lung.

The Cohen Group found no studies evaluating human inhalation of dipropylene glycol, but other toxicological information and its chemical similarity to propylene glycol indicate that it should be regarded as posing similar (negligible) health risks. Dipropylene glycol has been found not to be irritating to the eyes or skin of rabbits.

There is also very limited toxicological information regarding diethylene glycol. From the limited data, it appears that it may be somewhat more toxic than triethylene glycol and propylene glycol, but still of very low toxicity.

Glycerin also may be considered of very low toxicity. As is stated in the Documentation of the Threshold Limit Values and Biological Exposure Indices, Sixth Edition, published by the American Conference of Governmental Hygienists (ACGIH), glycerin "mist is considered a nuisance particulate which seems to have little adverse effect on the lung and does not produce significant organic disease or toxic effects when exposures are kept under reasonable control."

Butylene glycol is different from the former compounds in that there are four structurally different “isomers” of butylene glycol, identified as the 1,2-, 1,3-, 1,4-, and 2,3-butanediols. Based upon the findings of our research, it appears that only the 1,3-butanediol isomer is widely used as a fogging agent. The 1,3- isomer is low in toxicity and has been proposed for cosmetic and pharmaceutical applications. The 1,2-isomer is similar in potential toxicity to the 1,3- isomer. The 1,4- isomer is approximately 10 times more toxic than the 1,3- and 1,2-isomers, while the toxicity of the 2,3- isomer is greater than the 1,3- and 1,2-isomers but less than the 1,4-isomer. The 1,3- and 1,4- isomers are not significantly irritating to the eyes, skin or mucous membranes, and not significantly skin absorbable. The 1,2-isomer is not significantly irritating to skin but is irritating to the eyes.

There is some evidence that propylene glycol can produce allergic reactions in particularly sensitive individuals. However, such reactions are very rare. Propylene glycol continues to be widely used in pharmaceuticals and cosmetics.

RELEVANT EXPOSURE LIMITS OR GUIDELINES

Definition of Terms

PEL

Permissible exposure limits (PEL's) indicate average airborne contaminant levels to which it is believed nearly all workers may be exposed without significant ill effect. The U. S. Occupational Safety and Health Administration (OSHA) requires compliance with PEL's under Title 29 of the Code of Federal Regulations, Part 1910.1000. The State of California requires compliance with PEL's established in Title 8 of the California Code of Regulations, General Industry Safety Order 5155. Cal/OSHA PEL's have been included because they have been updated several times since their initial promulgation. With a few exceptions, and none relevant to this project, the federal PEL's have not been updated since initial promulgation.

TLV

Another set of occupational exposure limits are the Threshold Limit Values (TLV's) recommended by the American Conference of Governmental Industrial Hygienists (ACGIH) as guidelines for safe work practices.

TWA

PEL and TLV values are typically expressed as 8-hour time-weighted averages (TWA's) defined as average airborne concentrations for an 8-hour work day and a 40 hour work week, to which nearly all workers may be repeatedly exposed, day after day, without adverse effect.

STEL

STEL's (Short Term Exposure Limits) have been established for chemicals to which short term exposure may produce deleterious health effects. STEL's are typically 15-minute time-weighted average exposures which should not be exceeded at any time during a work day, even if the 8-hour TWA is below the TLV. STEL's have not been established for any of the glycols of interest.

Ceiling Limit

Ceiling limits are concentrations which are not to be exceeded even instantaneously. Ceiling limits have been established for some chemicals to which even momentary exposure above a certain level can produce significant health effects.

ppm

Parts per million (ppm) indicates molecules of the agent of interest per million molecules air. Ppm is the unit of choice when the airborne contaminant is a vapor (i.e., an airborne dispersion of a chemical that is liquid at normal environmental temperatures and pressures, becoming airborne due to a change in temperature and/or pressure).

mg/m³

Milligrams per cubic meter (mg/m³) indicates milligrams of an aerosol per cubic meter of air; it is the unit of choice for dusts, fumes, smokes, mists and fogs which have been rendered airborne by man's or nature's actions.

Please note that a smoke is produced by the incomplete combustion of a carbon-based material, such as coal, tobacco, wood or oil. Accordingly, even though glycol fogs are commonly referred to as smokes by the individuals involved in theatrical productions, glycol fogs are not smokes.

Exposure Limits and Guidelines

Although ethylene glycol is not one of the glycols investigated, it is consistently referenced as the basis for limits established or recommended for the glycols of interest and is therefore included below.

Ethylene Glycol

- State of California OSHA PEL (Ceiling Limit) - 50 ppm or 125 mg/m³ (vapor)
- U.S. OSHA has not established a PEL for ethylene glycol, however the vacated 1989 U.S. OSHA proposed PEL (8-hour TWA) was 50 ppm or 125 mg/m³
- NIOSH submitted written testimony to OSHA in 1988 stating that ethylene glycol produces respiratory irritation in humans at the level proposed (50 ppm/125 mg/m³)
- American Conference of Governmental Industrial Hygienist Threshold Limit Value (Ceiling Limit) - 100 mg/m³ (aerosol)

Propylene Glycol

- American Industrial Hygiene Association Workplace Environmental Exposure Level (8-hour TWA) - 50 ppm (total vapor and aerosol), 10 mg/m³ (aerosol) - 1985 [note: 50 ppm equates to approximately 220 mg/m³]
- United Kingdom Health and Safety Executive EH40/93 (8-hour TWA) - 470 mg/m³ (vapor), 10 mg/m³ (particulate)
- In a June 6, 1995, letter from James P. Kehrer, Ph.D., Head, Division of Pharmacology and Toxicology at The University of Texas at Austin, to Lowell R. Fowler of High End Systems, Dr. Kehrer reviews the toxicity of propylene glycol and triethylene glycol. The letter cites the UK standard noted above and states "the limit for these glycols is 470 mg/m³ for 8 hours. While similar standards have not been established by any United States regulatory agency, I believe this limit, which exceeds the maximum levels in fogs by a factor of 20, is reasonable." Dr. Kehrer was apparently unaware that, although the 1990 UK standard of 156 mg/m³ was established solely for the vapor state, in 1993 separate standards of 470 mg/m³ and 10 mg/m³ were established for the vapor and aerosol, respectively.

Diethylene Glycol

- American Industrial Hygiene Association Workplace Environmental Exposure Level (8-hour TWA) - 50 ppm (total vapor and aerosol), 10 mg/m³ (aerosol) - 1985 [note: 50 ppm equates to approximately 160 mg/m³]

Glycerin

- State of California OSHA PEL (8-hour TWA) - glycerin mist is regulated as "Particulates not otherwise regulated" at 10 mg/m³ (total) and 5 mg/m³ (respirable)
- U.S. OSHA has not established a PEL for glycerin, however the vacated 1989 U.S. OSHA proposed PEL (8-hour TWA) for glycerin mist was 10 mg/m³ (total) and 5 mg/m³ (respirable)
- Current U.S. OSHA PEL (8-hour TWA) for glycerin mist - 15 mg/m³ (total) and 5 mg/m³ (respirable)
- ACGIH TLV (8-hour TWA) - 10 mg/m³

No exposure limits or guidelines have been established or proposed for triethylene glycol, dipropylene glycol or the various isomers of butylene glycol.

Are Glycols in Fogs Vapors or Mists or Both?

As is noted in the prior section addressing established exposure limits and guidelines, several organizations/agencies have stipulated different allowable concentrations for the vapor and the aerosol states of the glycols of interest. In each case the allowable concentration for the vapor is more than ten times that established for the aerosol. Consequently, determining the physical state of the glycol present in the breathing zone of individuals exposed to the fog would appear to be important.

At ambient temperatures, the glycols of interest produce essentially no vapor (i.e., they have a very low "vapor pressure"). However, when the temperature of a solution is raised above the boiling point of its components (i.e., a glycol and water) by the heating element, the liquid is converted to a vapor, remaining so until the cooler temperature of the stage causes condensation into mist droplets. The temperatures of the heating elements in foggers typically range from 218° C to 370° C. The boiling points of the glycols of interest range from approximately 180° C to 290° C and the actual boiling points of fogger solutions vary with the type of glycol(s) and the percent water in the solution. [A Material Safety Data Sheet for High End Systems, Inc./ Lightwave Research "Atmospheres HQ Light Enhancement Fluid", containing propylene glycol, triethylene glycol, and water, notes a boiling point of 212-470° F, which equates to 100-243° C].

No matter what the composition of the solution, vaporization would be expected to be complete by the mean fogger heating element temperature of 294° C, given sufficient contact time. The intent of the fogger, however, is not to disperse a vapor into the environment; the vapor would have negligible light-refracting ability. Instead, the intent of the fogger is to produce a light-obscuring aerosol and the heating element is there to generate a vapor as a means of generating an aerosol with the desired characteristics.

Because molecules in the vapor state are individualized and effectively smaller than in the aggregate aerosol (mist/fog) state, they penetrate deeper into the lung. There, the molecules theoretically may affect lung tissue and/or be absorbed into the blood, affecting other "target" organs. Aerosol particles too large to penetrate deep into the lungs are caught in the upper respiratory tract, transported to the gastrointestinal tract, and ingested; available data indicate that ingestion of small amounts of the glycols of interest is safe. Consequently, establishing a different exposure limit for glycol vapors and aerosols generated by foggers would be sensible if:

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- 1) *It had been demonstrated that glycol vapors were present to a significant extent* (the visible fog demonstrates the presence of the aerosol). Though none of the data reviewed evaluate the extent to which a vapor component is present in theatrical fogs, it would be reasonable to assume that in environments which are highly saturated with the aerosol, some vapor would be present simply due to the vapor pressure of the glycol(s) present. It should be noted that, although the NIOSH sampling method includes serially arranged sampling media, one to capture the aerosol and one to capture the vapor, the results of monitoring for the two types of media are not presented separately (i.e., the total sample result is presented).
 - 2) *There was evidence that inhalation of the vapors of the glycols of interest posed a greater health hazard than inhalation of their aerosols.* Where animal or human inhalation toxicity data exist for the glycols, whether as a vapor or an aerosol, the conclusions of the studies are consistently that no significant inhalation hazard is posed at levels 5 to 10 times the maximum found in theatrical productions. Some studies evaluated vapor; others evaluated simultaneous exposure to both vapor and aerosol. None of the studies The Cohen Group reviewed expressly evaluated the differences in toxicity associated with the physical state of the glycol (i.e., vapor or aerosol). Further, The Cohen Group could find no justification for the two, different limits.
 - 3) *The sizes of glycol aerosol particles generated by foggers are too large to penetrate into the lungs (i.e., are not "respirable).* A Swedish study (cited in a 1990 report prepared by The Professional Lighting and Sound Association, United Kingdom, but not referenced) found aerosol particle size to range from 1 micron to 2.5 microns, both sufficiently small to be readily respirable. However, the Material Safety Data Sheet for "Atmospheres", cited above, indicates that, if respiratory protection is worn, it should be capable of removing particles in the 10 to 20 micron range; this size is somewhat larger than what is typically regarded as respirable.

In conclusion, although it is unknown to what extent glycol vapors are present in theatrical fogs, available evidence indicates that it is not of great consequence. There is no evidence that either poses a significant inhalation hazard at the concentrations found in theatrical productions.

A curious point related to the same topic is the consistently more conservative exposure limit established for the aerosol state in comparison to that established for the vapor state. Employing conventional wisdom, the opposite would be more reasonable. As noted above, unless aerosol particle size is consistently 10 microns or less (i.e., is respirable), it would be expected that the vapor would pose the greater hazard. Yet the Workplace Environmental Exposure Level (WEEL) established by the AIHA for propylene glycol total vapor and aerosol is 22 times that established for the aerosol alone, indicating that it is considerably safer to be exposed to the vapor and aerosol than the aerosol alone. Similarly, the AIHA has established a WEEL for diethylene

glycol total vapor and aerosol that is 16 times that established for the aerosol alone. Finally, the United Kingdom standard for propylene glycol vapor is 47 times that established for the aerosol.

The WEEL's for propylene glycol and diethylene glycol were established by the AIHA in 1985. We spoke with the individual who chaired the WEEL committee at that time. He could not recall why different levels were established for the total aerosol and vapor versus the aerosol alone, but stated that the rationale was in all likelihood to be found in supportive documents generated by the committee, which are presently archived at the AIHA national headquarters in Fairfax, Virginia. Since such research was outside the scope of this project, no further research was conducted.

Are Other Chemical Compounds Formed during the Fogging Process?

It appears to depend upon the temperature and, possibly, the nature of the heating element

Of particular interest are acrolein, acetaldehyde, and formaldehyde, known to be potential degradation products of the glycols and all established to be strongly irritating to the eyes and respiratory tract. One aspect of Revised Health Hazard Evaluation Interim Report No. 90-355, NIOSH was the analysis of air samples (headspace samples) collected immediately above bulk samples of fogger solutions heated to 290°, 315°, and 370° C. These temperatures corresponded to the temperatures of the heating elements in the foggers used in the theatrical productions monitored. While acrolein, formaldehyde and acetaldehyde were not detected at the lower two temperatures, they were found to be present at 370° C.

In the same report and in Health Hazard Evaluation Report 90-0355-2449, NIOSH presented data from personal breathing zone and area air samples collected during Broadway theatrical productions employing fog. Although the "Summary" reports that acrolein, acetaldehyde, and formaldehyde were not detected in any of the samples collected in either of the studies, the data tables associated with the reports indicate that very low levels of formaldehyde and acetaldehyde were detected in most area samples collected in 1991 and some in 1993; the 1991 data indicate that the compounds were also detected in the sampling media and quality control "field blanks", and therefore are considered suspect by NIOSH. The "Results" section of NIOSH report 90-0355-2449 states that formaldehyde concentrations were found to range from <0.002 to 0.04 ppm. It also states "These concentrations are well below the OSHA and ACGIH exposure limits and are typical of concentrations which NIOSH investigators have measured in non-industrial work places."

Several different types of foggers were used in the productions investigated by NIOSH in 1991 (report 90-0355), with the temperatures of the heating elements in the units reported as 290° C to 370° C (555° F to 700° F). No fogger unit or heating element temperature data were provided for the follow-up study (90-355-2449).

Notably, NIOSH report 90-355-2449 includes the following statement: “No decomposition products were observed either in the headspace analysis of the heated bulk samples or in the field blanks collected in this follow-up survey [note: temperature was not reported]. However, in the initial 1991 survey, decomposition products (such as acrolein and acetaldehyde) were detected by NIOSH in a laboratory setting when a glycol-based fog solution was heated to approximately 700° F. (One of the fog systems in use during the 1991 survey heated the fluid to this temperature). It should be noted that these decomposition products **were not** detected in the PBZ and GA air samples collected during the play in which this fog system was used.” The emphasis was added by NIOSH. The abbreviations “PBZ” and “GA” denote “personal breathing zone” and “general area,” respectively.

Air samples collected by NIOSH in 1993 (HETA 94-0103) in a mock environment constructed at the facilities of Lightwave Research/High End Systems, Inc. detected volatile organic compounds (VOC’s) and, in the most fog-dense test, formaldehyde. However, VOC’s and formaldehyde were also detected in an equivalent concentration in an office area outside the fogged area. Since VOC’s and formaldehyde are commonly found in interior environments, and are known to originate from building furnishings and finishes, no conclusion was drawn concerning the source of the chemical compounds.

Gregory Burr, CIH, lead NIOSH investigator in several studies of fogging agents, stated in a telephone conversation that he believed hollow coil-type heating elements might be more prone to producing degradation products due to the greater residence time of solutions, particularly during repeated start-and-stop usage of a fogger; Mr. Burr stated that this was only a tentative theory and that there presently is no evidence to substantiate it.

The aforementioned 1990 British report prepared by The Professional Lighting and Sound Association refers to two studies reporting degradation products in the air during operation of foggers. References were not included in the report and The Cohen Group has not reviewed the studies, their methodology or the nature and temperatures of the fog-generating processes. Consequently, we cannot comment upon the findings of the studies, which reportedly were:

- The “Swedish National Testing Institute analyzed the smoke for the presence of aldehydes and acetone, but all of these were orders of magnitude below the British HSE Guidelines.”
- The (British) National Occupational Hygiene Service Ltd. found formaldehyde concentrations associated with fogs, with “an increase in density produced in increase in formaldehyde, reaching 0.11 mg/m³ at 30% transmittance (estimated).”

CONCLUSIONS

- 1) The recommended exposure guidelines presented in this report are both highly conservative and readily achievable. They are conservative because there is no evidence that concentrations 10 or 20 times higher will produce adverse health effects in healthy individuals. They are readily achievable because typical concentrations of glycols during theatrical productions are less than 50% of the recommended guidelines. In addition, the recommended exposure guidelines are predicated as 8-hour time-weighted averages; the exposures of performers would in all likelihood be for less than one-half this duration. Although concentrations of glycols in mock environments with atypically dense fog have exceeded the guideline concentrations, all available data indicate that the average exposure to a performer in a fogged production would be well below the recommended guidelines.
- 2) Although our research indicates that only the 1,3-butanediol isomer of butylene glycol is used in fogging solutions, manufacturers are encouraged to continue this practice. Given that the 2,3- isomer and, particularly, the 1,4-isomer are significantly more toxic, their use in fogging solutions should be avoided.
- 3) The chemical nature of glycols is such that prolonged or repeated contact with a glycol mist is likely to dry-out moist tissues (i.e., the mucous membranes of the upper respiratory tract and, possibly, the eye). In accordance with the requirements of the Hazard Communication Standard (40 CFR 1910.1200), performers and other personnel working in productions where exposure to fogs is likely must be apprised of the potential outcome of such exposures.
- 4) Although we found no evidence that skin contact resulting from airborne theatrical fogs has resulted in skin irritation or allergic sensitization, performers should also be informed that unusually sensitive individuals may experience such effects.
- 5) Individuals with pre-existing respiratory conditions may be more prone to experience respiratory irritation when exposed to theatrical fogs. Although we believe the recommended exposure guidelines to be sufficiently protective to minimize the likelihood of any adverse effect, such individuals should be counseled to seek medical advice prior to prolonged or repeated exposure to theatrical fogs.
- 6) Because we are in agreement, we present the conclusion of the 1993 NIOSH investigation of theatrical fog usage during Broadway productions:

“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 aerosolized glycols and mineral oil, could have irritating 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.”

RECOMMENDATIONS FOR FURTHER RESEARCH

The following issues were raised but not resolved in this report. The first issue is the one that is the most intriguing and, if there is a substantial justification for the difference, most likely to require modification of the recommended exposure guidelines presented in this report.

- 1) *Why have organizations/agencies stipulated different allowable concentrations for the vapor and the aerosol states of glycols?*
- 2) *Do different types of heating elements differ in their potential for degradation of glycol fogging solutions and, if so, is one type significantly more hazardous than another (i.e., does it produce toxic compounds in potentially significant airborne concentrations)?*
- 3) *Is there an optimum temperature range for a given glycol solution which both produces the desired fog and minimizes the extent of glycol degradation? Are there circumstances where a fogger may be operated above such a range, potentially producing airborne degradation products in toxicologically significant concentrations?*
- 4) *Are other types of foggers (e.g., ultrasonic foggers) in use and, if so, what is the nature and concentration of the constituents of the resultant fog?*

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Attachment A - References

The following reference materials provided information that substantially contributed to the findings and conclusions of this report. Other references, including journal articles and several hundred downloaded database summary references, that were reviewed but which did not materially contribute to the findings and conclusions of the report are not listed.

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ADDENDUM TO
REPORT OF FINDINGS

RECOMMENDED EXPOSURE GUIDELINES
FOR GLYCOL FOGGING AGENTS

Project No. 6070-1001

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Date of Addendum: May 9, 1997

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RECOMMENDATIONS FOR FURTHER RESEARCH

Three areas in which further research is recommended are:

- 1) *Why have organizations/agencies stipulated different allowable concentrations for the vapor and the aerosol states of glycols?*

We recommend that this issue initially be researched through review of documents and committee records developed by the Workplace Environmental Exposure Level Committee of the American Industrial Hygiene Association (AIHA). During the initial phase of our research, we contacted a past member of the committee who believed that the documents and records may be available for review at the headquarters of the AIHA.

Similar records may be also be available from the United Kingdom Health and Safety Executive.

- 2) *Given that the exposure guidelines proposed in our report, and presented in the table found on page 1 of the report, are proposed for healthy adults, what modifications to the guidelines are appropriate for individuals who are not healthy adults? For example, what exposure guidelines are appropriate for children, for infants, for the aged, and for individuals with a pre-existing health condition, particularly a health condition that may be exacerbated by exposure to a known respiratory irritant?*

It is recommended that this issue be researched and resolved by a D.A.B.T.-certified toxicologist with a demonstrated history of establishing exposure guidelines for public health, not just the occupational workforce. Recognize, however, that this issue may be very difficult, if not impossible to address generically, and therefore only can be handled on a case-by-case basis.

- 3) *When evaluating exposure to glycol fogging agents, is it appropriate to solely rely upon measurements of airborne concentrations of the major glycol(s)? Are there conditions under which other airborne contaminants (e.g., thermal degradation products, trace contaminants) generated in fogs are present in levels posing a potential health hazard?*

It is recommended that the following issues be investigated through product testing and/or manufacturer research:

- Do different types of heating elements differ in their potential for degradation of glycol fogging solutions and, if so, is one type significantly more hazardous than another (i.e., does it produce toxic compounds in potentially significant airborne concentrations)?
- Is there an optimum temperature range for a given glycol solution which both produces the desired fog and minimizes the extent of glycol degradation? Are there circumstances where a fogger may be operated above such a range, potentially producing airborne degradation products in toxicologically significant concentrations?

The testing protocol employed by NIOSH and Lightwave Research/High End Systems, Inc. in their 1993 study, modified to include different fog-generating systems and the potential range of operating temperatures would be appropriate to resolve these questions.

- 4) *Are types of foggers not addressed in this literature review (e.g., ultrasonic foggers) in use and, if so, what is the nature and concentration of the constituents of the resultant fog?*

The testing protocol employed by NIOSH and Lightwave Research/High End Systems, Inc. in their 1993 study, modified to include different fog-generating systems would be appropriate to resolve this question.

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