BY KARL G. RULING

No simple answers: The fog of fog details

PHOTO: JAY HUANG 2014

California coastal fog regularly flows in through the Golden Gate, obscuring the Golden Gate Bridge.

I OFTEN GET QUESTIONS looking for a simple answer about fog. The ones I will write about now are those asking why one organization offers one set of acceptable fogs use rules, but another offers something different—and why is no one talking about $PM_{2.5}$ and PM_{10}? Theatrical fog is fog, and chemicals are chemicals, so why are there any differences? The differences come from the different situations being considered, the different criteria used, and simply because different people make different judgments at different times.

"Theatrical fog is fog, and chemicals are chemicals, so why are there any differences?"

$PM_{2.5}$ and PM_{10} particles

A comment offered during last year's public review of *ANSI E1.23, Entertainment Technology—Design, Execution, and Maintenance of Atmospheric Effects*, triggered an email exchange in which a commenter asked ". . . what ESTA's opinion is on the health effects of $PM_{2.5}$ and PM_{10}, which are created by smoke and haze machines?" The commenter was not the first to ask about theatrical fog particle size, calling out $PM_{2.5}$ and PM_{10}. Those are metrics used by the Environmental Protection Agency in the National Ambient Air Quality Standards (NAAQS) for gauging outdoor air pollution. Outdoor air pollution criteria were established by the EPA for outdoor air quality, not for theatrical fog. The concerns and acceptable criteria are different.

$PM_{2.5}$ and PM_{10} mean particulate matter (PM) characterized by size. Vapor or small solid things in the air are considered particulate matter. If its aerodynamic diameter is less than or equal to 2.5 µm, it's $PM_{2.5}$; if its aerodynamic diameter is less than or equal to 10 µm, it's PM_{10}. (There is overlap.) Theatrical fog machines produce droplets within this range. Hazes are at the smaller end. "Smoke" effects are at the larger end. The droplets are made of a variety of liquids: water, glycerin, glycol (eight different glycols are commonly used), and highly refined mineral oil. Fog consists of tiny droplets of varying size.

The concern for particle size comes from EPA's NAAQS (40 CFR Part 50), which are sometimes cited by air quality consultants as guidelines due to the lack of occupational exposure limits for $PM_{2.5}$ and PM_{10}. The EPA is charged with regulating outdoor air quality to control pollutants. It sets two type of standards: Primary standards provide public health protection for people; secondary standards provide protection against decreased visibility and damage to animals, crops, and buildings. The EPA primary standards regulate six of the most common outdoor air pollutants to establish air quality: carbon monoxide, lead, ozone, nitrogen dioxide, sulfur dioxide, and particle pollution. The particle pollution limits are set by particle size— $PM_{2.5}$ and PM_{10}. It's a simple measure of air quality, but it's not nuanced.

Monitoring particulate matter by size

alone, disregarding content, would be a very blunt tool for measuring air quality. In San Francisco, at the end of each summer day, fog flows inland over the hills and through the Golden Gate. Fog is primarily water vapor and water is not usually considered a health hazard. The fog obscures the Farallon Islands, so it decreases visibility, but the fog itself is beautiful. Never the less, California coastal fog is particulate matter, much of it falling within PM_{10}, a size range within the scope of the one of the EPA measures of air quality.

"All these rules and guidance documents have the same goal: a stage or studio that is both safe to work in and that feels safe to work in."

I offer California coastal fog, not as a *reductio ad absurdum* argument, but as an example of how blunt a tool particle size alone is. It is a blunt tool, but is a reasonable tool for controlling outdoor air quality for an entire nation. The particles to be included in the EPA's $PM_{2.5}$ and PM_{10} monitoring could be anything, and indeed what's actually in the air could be anything. The particulates in the air are likely to be different near a major LA freeway than in the middle of a Nebraska wheat field. The population that might be exposed to these particulates is also undefined. Who might be downwind of the freeway or the wheat field, and what are their chronic health problems? The EPA is charged with protecting the public—babies, the elderly, sick people, the healthy—and the secondary standards have the EPA taking care of animals, plants, and buildings. When you don't know who might be exposed or to what they might be exposed, setting the exposure level as close to zero as practical is reasonable—particularly when there is nothing to be gained from uncontrolled emissions. People enjoy a view. A brown haze obliterating the view of the Pacific Ocean from Griffith Park does not enhance quality of life.

The situation with atmospheric effects on stage and in studios is radically different from the outdoor environment. First, we know what is being put into the air; it's not undefined. With a properly designed and operated fog or haze machine, the fluid that goes into the machine and what comes out of the machine are known. Second, we have some control over the exposed population. The cast and crew on a show or movie-shoot is known—personally, by name. There is less control over who might be in the audience of a live event, but even then, the population is not totally undefined. The age range is somewhat restricted (children under 4 generally are not permitted in Broadway theatres), and few seriously ill people are going to the theatre. There are few animals and plants to worry about, but, if there are any, they are known, as are the building and parts of a building that will be affected. Who and what is affected by the effect is not undefined.

Finally, we want the air to be cloudy, not clear! Theatrical fog is useful for simulating smoke, and far safer than the real thing. On stages and in studios, it makes light beams visible in the air, and hides details in the shadows, making dark scenes appear to be in a void. In motion picture work, haze "softens the digital edge," as some say, enhancing the picture quality. Protocols for controlling indoor theatrical atmospheric effects will be different from the protocols for ambient outdoor air quality; the situations are different. More factors can be controlled with theatrical effects. The established protocols for the reasonably safe use of indoor atmosphere effects consider the exposed population, the toxicity of the fog-making material, the exposure concentration, and the exposure time—which are critical for managing a safe show environment.

DEG and PEG

There are many guidelines and protocols for controlling theatrical atmospheric effects. Besides state and national occupational safety and health regulations, the main ones are *ANSI E1.5, Entertainment Technology – Theatrical Fog Made with Aqueous Solutions of Di- And Trihydric Alcohols*, *ANSI E1.23, Entertainment Technology – Design, Execution, and Maintenance of Atmospheric Effects*, and industry labor contracts and work rules, including Actors' Equity's *Equipment-Based Guidelines for the Use of Theatrical Smoke and Haze,* ActSafe's *Motion Picture Safety Bulletin 10,* and the Contract Services Administration Trust Fund's *Safety Bulletin #10, Guidelines Regarding the Use of Artificially Created Atmospheric Fog & Haze.* The most comprehensive for outlining how to design, execute, and maintain safe atmospheric effects is *ANSI E1.23*, but *ANSI E1.23* does not set exposure levels or exposure times. It requires the atmospheric effect designer to do that work, to plan the effect so that no one is over-exposed to any of the fluids or gases used; the designer has to look at other documents and assess the desired effect and the situation to come to reasonable exposure limits.

"Why not avoid all these exposure limits by using something that is totally non-toxic? Answer: Because nothing is totally non-toxic."

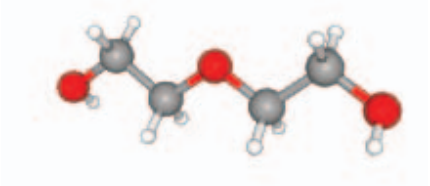
All these rules and guidance documents have the same goal: a stage or studio that is both safe to work in and that feels safe to work in. However, the recommendations are not the same. *ANSI E1.5* and the Actors' Equity *Guidelines* are consistent with each other. The two *10* bulletins are consistent with each other, but are different from *E1.5* and the *Guidelines*. The *10* bulletins recommend against using diethylene glycol (DEG) and lists polyethylene glycol (PEG) as an acceptable fog fluid. *ANSI E1.5* and the *Guidelines* list DEG as acceptable and make no mention of PEG. Why the differences? Different questions were asked at different times, and different people gave different answers.

Highly refined mineral oil

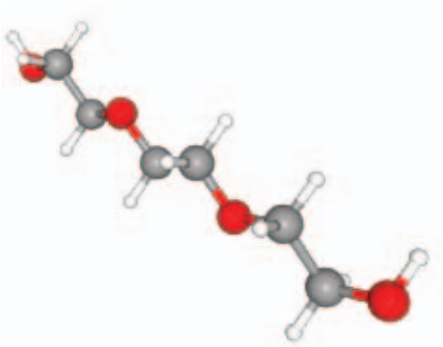
All the standards and workplace rules for oil-based fog are for *highly refined* mineral oil. "Mineral oil" is a term even looser than polyethylene glycol, and includes just about anything not derived from vegetables or animals that might be used as a lubricant. Usually mineral oil is derived from crude oil by fractional distillation, cracking, and other processes that refine the crude oil into useful products.

Crude oil is a chemical stew created by the long, slow decomposition of marine animals and plants over millions of years underground. Crude oil is a mixture of many, many different hydrocarbons: the most common are alkanes, cycloalkanes, aromatic hydrocarbons, and asphaltenes. Each petroleum variety (e.g. West Texas Intermediate, Brent Crude) has its own mix of molecules, which define its physical and chemical properties, and its market value.

Highly refined mineral oil, used in fog fluids, food, and medicines, contains pure alkanes, chains of carbon atoms linked to each other by single covalent bonds, with all the other bonds linking to hydrogen atoms. That's all. The oil has been refined and refined multiple times to ensure the oil only contains alkanes. Unrefined or partially refined mineral oils may be mostly alkanes, but not entirely. They probably will include polycyclic aromatic hydrocarbons, which are linked to various types of cancer. The composition of unrefined or partially refined mineral oils is undefined—and with this we are back to a situation analogous to the undefined particulates in the EPA's outdoor ambient air quality standards. When something might be dangerous—and "carcinogenic" really alarms people—the safest thing to do is set the exposure level as low as possible. With oil-based theatrical fogs, "as low as possible" means *no unrefined or partially refined mineral oil*, highly refined mineral oil only.



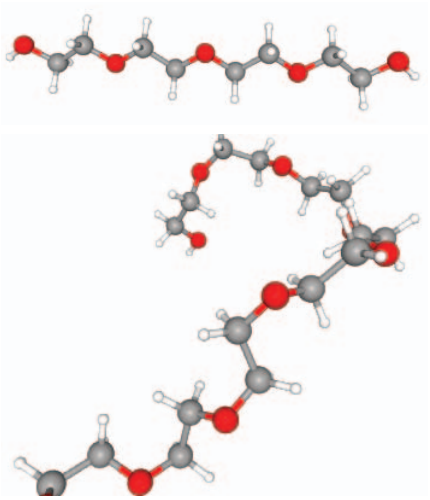
Diethylene glycol (DEG) is a short chain. It is prohibited from being used in atmospheric effects by some regulations and work rules, but is permitted by others. (These ball and stick images are from PubChem, a National Institutes of Health website.)



Triethylene glycol (TEG) is a longer, less volatile glycol than diethylene glycol. It is a common component of fog fluids.

Both *ANSI E1.5* and the Equity *Guidelines* were a response to the controversy over theatrical fog effects in the 1990s. *E1.5* is based on the Equity *Guidelines* and on the results of two scientific literature studies commissioned by ESTA in 1996. ESTA's Fog and Smoke Working Group gave two industrial hygiene firms a list of the glycols believed to be used in fog effects in New York theatres, which did not include PEG, and asked them for a search of scientific and other applicable literature for papers that help define safe inhalation exposure concentrations. A similar task was given by the Equity-League Pension and Health Trust Funds to researchers from Department of Community and Preventive Medicine of Mount Sinai School of Medicine and the ENVIRON International Corporation, with the additional task of objectively determining how atmospheric effects affect performers—a special population with health concerns different from those of general industry workers. The results of the literature searches done by the Certified Industrial Hygienists and the Equity-League study resulted in establishing the TWA and ceiling limits for the glycols listed in *ANSI E1.5*. A later study of glycerin used in the fog on *Mamma Mia!* on Broadway resulted in the addition of TWA and ceiling limits for glycerin.

DEG is listed in *E1.5* and the Equity *Guidelines* because it was used in fogs on Broadway in the 1990s, and none of the two CIH literature searches commissioned by ESTA nor the literature searches done by the Mt. Sinai and ENVIRON researchers for the Equity-League Pension and Health Trust Funds turned up reports that suggested it was unsafe for people at the likely exposure levels. The two *10* guidelines say not to use it, but don't say why. (They're terse guidelines.) However, a more recent document, *Theatrical Fog Exposure Assessment: Methods, Exposure Limits, and Health Effects – Literature Review,* commissioned by CSATF and carried out by the Colden Corporation and reviewed by The Phylmar Group in 2017, says ". . . animal studies for diethylene glycol, ethylene glycol, and 1,4-butylene glycol revealed concerning health effects, and we recommend not using fogging fluids containing these ingredients." (Ethylene glycol and 1,4-butylene glycol aren't listed as acceptable fog fluids in *ANSI E1.5*.) The Colden report doesn't cite a critical study that was not available to the earlier researchers, but the Colden report is looking at the issue differently. It recommends what *should* be used; the earlier reports took the glycols used as given and offered advice on the *limits* to use them safely. These are different approaches and lead to different conclusions.



Tetraethylene glycol and octaethylene glycol are two of a long list of glycols that could be called polyethylene glycol (PEG).

The two motion picture industry *10* documents and the Colden report list polyethylene glycol (PEG) as an acceptable fog material. *ANSI E1.5* and the Equity *Guidelines* don't list it, but it is listed as a fog-making fluid within the scope of *ANSI E1.23*, the standard for planning atmospheric effects. Why the differences?

ANSI E1.5 and the Equity *Guidelines* don't list PEG because it wasn't included in ESTA's CIH literature searches or the Equity/League study. It wasn't used in fogs on Broadway shows in the 1990s. Shortly after the first edition of *ANSI E1.5* was published, the product manager for a major fog/haze manufacturer said that his company was making a haze machine that used PEG 200. Could PEG 200 be added to the list of glycols in *E1.5*? Yes, if we had information that showed what exposure limits would be appropriate for performers. Would he provide it? The Fog and Smoke Working Group didn't receive that information, so PEG isn't listed in *ANSI E1.5*.

Polyethylene glycol is used in fog and haze fluids, particularly in fluids that are used in the motion picture industry; PEG is on the acceptable lists of the two *10* documents. The Colden report lists it and cites studies showing relatively low toxicity when tested on animals. The table at the back of the report shows PEG having the same German MAK and Work Safe British Columbia exposure limits as triethylene glycol, which is included in *ANSI E1.5*. With additional research, it's possible the limits in *ANSI E1.5* for triethylene glycol could be extended to polyethylene glycol, although currently we don't have data for how it affects performers.

Triethylene glycol and polyethylene glycol are related organic compounds. Triethylene glycol is a glycol with three ethylene monomers joined by oxygen atoms between them. Tetraethylene glycol has four monomers, pentaethylene has five, and so on. Polyethylene glycol has many ethylene monomers—an unspecified number; the name is usually used to describe a mixture of glycols with molecules having four or more ethylene monomers. The average molecular weight of the molecules in the mixture sometimes is given a number. PEG 200 could have a lot of tetraethylene glycol (194 grams/mol) mixed with enough heavier isomers to raise the average weight to 200 grams/mol. As the molecules of polyethylene glycol get heavier and longer, the glycols become less liquid, more waxy, eventually being solid. Polyethylene glycol 3350 is a dry powder, and the main ingredient in powdered MiraLax.

It's not clear what formulation of PEG is referenced in the two *10* guidelines. There are hundreds of isomers that can be called polyethylene glycol. *ANSI E1.23* lists PEG 200 to 400 in its scope, since this covers a range of liquid glycols usually used in cosmetics and pharmaceuticals. *ANSI E1.23* doesn't specify exposure limits, but it does list materials appropriate for atmospheric effects, so we avoid problems with someone doing something stupid but waiving responsibility, saying he followed the ESTA standard. There are many things that could be used but that would be problematic. Consider peanut oil. It's organic and sustainable! There's an OSHA standard for vegetable oil exposure. However, as a fog fluid, it would send people with peanut allergies to the hospital. We want to avoid that.

Why not avoid all these exposure limits by using something that is totally non-toxic? Answer: Because nothing is totally non-toxic. Everything is potentially toxic at some exposure level. (Google or Bing "Hold your wee for a Wii," "oxygen toxicity," or "salt poisoning." The stories might be funny if people hadn't died.) Besides that, even if the fog material used has very low toxicity, equipment maintenance and cleaning will be important for ensuring it's used safely. Thinking, "Oh, it's non-toxic," is excellent for encouraging shoddy work.

Which standard, regulation, or guideline is right?

Trick question! They all have the same goal: a stage or studio that is safe to work in and that feels safe to work in. They are based on the information available at the time they were written, with consideration for the working environments and industry cultures. Ask for professional guidance if you are not sure. Use the ones you legally and contractually must use, and that your production team agrees are appropriate. They are not the same, but conscientiously followed, they will achieve the same results: avoidance of expensive arguments, protection of people, and aesthetically useful atmospheric effects. ■

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~ Karl G. Ruling