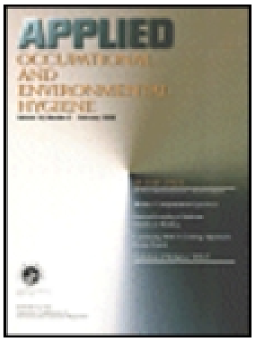

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Occupational Health Risks Associated with the Use of Irritant Smoke for Qualitative Fit Testing of Respirators

Dawn Tharr, Column Editor

Report by Steven W. Lenhart and G. E. Burroughs

Introduction

The National Institute for Occupational Safety and Health (NIOSH) conducted a Health Hazard Evaluation (HHE) in response to a request from a fire chief of a municipal fire department. The HHE request was received after four fire fighters reported experiencing either skin irritation or eye irritation as a result of qualitative fit tests using irritant smoke. One of these fire fighters had eye irritation severe enough to require treatment at a hospital. The issues addressed in this case study are: (1) evaluation of the health risks associated with the use of irritant smoke for qualitatively fit-testing respirator facepieces and (2) recommendation of an alternative method that should be used for fit testing the facepieces of self-contained breathing apparatuses (SCBA).

Background

The National Fire Protection Association's (NFPA) Standard on Fire Department Occupational Safety and Health Program (NFPA 1500) requires that "the facepiece seal capability of each member qualified to use a self-contained breathing apparatus (SCBA) shall be verified by qualitative fit testing on an annual basis and whenever new types of SCBA or facepieces are issued."[1] NFPA 1500 further requires that open-circuit SCBA be positive pressure and meet the requirements of NFPA 1981, *Standard on Open-Circuit Self-Contained Breathing Apparatus for Fire Fighters.*[2] Procedures for conducting qualitative fit tests of positive pressure SCBA are incorporated in NFPA 1500 by reference to American National Standards Institute (ANSI) standard Z88.5, *Practices for Respiratory Protection for the Fire Service,* which requires the use of an irritant fume or odor test.[3] ANSI Z88.5 also requires that fit tests "be conducted using operating SCBA and not just the facepiece and breathing hose disconnected from the rest of the system."[3]

In the case of the municipal fire department requesting the HHE, each of 186 fire fighters was fit tested in 1992 while wearing an SCBA (with nose cup) operated in the pressure-demand mode. The SCBA worn was the MSA Ultralite™ (Mine Safety Appliances Company, Pittsburgh, Pennsylvania). This SCBA is a 30-minute device (NIOSH/MSHA Approval Number TC-13F-138) and does not have a demand or donning mode. The fit testing method used by the fire department involved puffing irritant smoke from air flow indicator tubes into a test hood which encompassed the fire fighter's head and the SCBA's facepiece. The indicator tubes contain stannic chloride ($SnCl_4$), which reacts with ambient humidity to liberate a white hydrochloric acid fume and tin compounds.[4] During each fit test a series of exercises was performed consisting of: (1) normal breathing, (2) deep breathing, (3) turning the head from side-to-side, (4) nodding the head up and down, (5) talking, and (6) frowning.

Methods

The health risks associated with the use of irritant smoke were evaluated by conducting particle size analysis of the "smoke" and measuring the concentration of hydrogen chloride produced by air flow indicator tubes.

Particle Size Measurements

Particle size measurements[5] of the aerosol emitted from the smoke tubes were conducted at the request of NIOSH by researchers from Los Alamos National Laboratory in New Mexico using two different laser light-scattering instruments. Initially, four samples were collected and analyzed using a Model HSLAS laser aerosol spectrophotometer (Particle Measuring Systems, Boulder, Colorado), which measures particles ranging from 0.065 μm to 1.0 μm. An additional five measurements were made with a Model 209D MET-1 instrument (Grants Pass, Oregon), which measures particles ranging from ≥ 0.1 μm to ≤ 5.0 μm. All samples were collected from a flow system of clean filtered air. The smoke tube was operated with the supplied squeeze bulb to inject a bolus of smoke into the flow stream. Room air was used with no attempt to control humidity. The flow system provided a rapid dilution of the smoke with clean filtered air. Each sample was extracted isokinetically for analysis by each of the light-scattering instruments used.

Hydrogen Chloride Measurements

Hydrogen chloride measurements were made at NIOSH using a Miran 1A Portable Ambient Air Monitor (The Foxboro Company, Foxboro, Massachusetts) operated at a pathlength of 20.25 m and an analytical wavelength of 3.4 μm. A 28-inch section of ⅜ inch (inside diameter) flexible tubing was connected from the inlet of the Miran to a 6-inch section of ¼ inch tubing which in turn was attached on one side of a full-facepiece air-purifying respirator positioned on the face of a mannequin. Because the aerosol being tested was suspected to consist of submicrometer particles, the effect of wall losses of particles to the inner surface of the tubing was assumed to be essentially negligible. To protect the NIOSH investigators from exposure to the concentrations of hydrogen chloride produced during testing, the mannequin and respirator were placed inside an operating laboratory fume hood. Testing was conducted on a day with low relative humidity and on a day with high relative humidity. Measurements were made with a smoke tube held at various distances from the inlet of the tubing leading to the Miran. Measurements were also made with a test hood encompassing the respirator and mannequin's head. Irritant smoke was puffed into the hood by placing the tip of the smoke tube just inside the small-diameter hole provided in the hood.

Hydrogen Chloride

Hydrogen chloride (CAS number 7647-01-0) is a strong irritant of the eyes, mucous membranes, and skin.[6] "Hydrogen chloride is treated as a material with good warning properties in part because of its immediate irritant effects to the eyes in humans. Grant[7] suggests the protective response is so strong that humans rarely have been submitted to damaging concentrations."[8] Inhalation of hydrogen chloride at concentrations of 5 ppm or more is immediately irritating to the nose and throat.[9] In addition to upper respiratory tract irritation, short-term exposure to relatively low concentrations can also cause coughing and choking.[10] Inhalation exposure of male volunteers to hydrogen chloride at concentrations between 50 ppm and 100 ppm for 1 hour were reported as barely tolerable, and 10 ppm was the maximal concentration acceptable for prolonged exposure.[11] The NIOSH recommended exposure limit (REL), the Occupational Safety and Health Administration permissible exposure limit (OSHA PEL), and the American Conference of Governmental Industrial Hygienists threshold limit value (ACGIH TLV) for hydrogen chloride are a ceiling limit of 5 ppm.[12–14] The ACGIH TLV is based "on the reports of respiratory irritation from short-term exposure to hydrogen chloride at 5 ppm and above."[15] "The ACGIH Chemical Substances TLV Committee holds to the opinion that TLVs based on physical irritation should be considered no less binding than those based on physical impairment. There is increasing evidence that physical irritation may initiate, promote or accelerate physical impairment through interaction with other chemical or biologic agents."[13]

NIOSH has also established an immediately dangerous to life and health (IDLH) value of 100 ppm for hydrogen chloride.[16] As defined by NIOSH, an IDLH value "represents the maximum concentration from which, in the event of respirator failure, one could escape within 30 minutes without a respirator and without experiencing any escape-impairing (e.g., severe eye irritation) or irreversible health effects. These values were determined during the Standards Completion Program only for the purpose of respirator selection."[16]

A concentration of 309 ppm has been reported as the level of hydrogen chloride causing a severe toxic endpoint in laboratory animals.[17] Severe toxic endpoints include intolerable irritation, incapacitation, and unconsciousness. Estimates of intolerable irritation were made using the RD_{50}, which represents the 10-minute exposure concentration producing a 50 percent respiratory rate decrease in mice. "A National Academy of Sciences (NAS) committee on toxicology recommended values below the RD_{50} to protect individuals in the event of an emergency exposure.[18] For example, for hydrogen chloride the NAS considered using one-tenth the RD_{50} to estimate an emergency exposure guidance level for military personnel but chose an even lower value (20 ppm) because of the paucity of human data."[19]

The International Agency for Research on Cancer (IARC) has concluded that hydrochloric acid is not classifiable as to its carcinogenicity to humans based on inadequate evidence for its carcinogenicity in humans and in experimental animals.[20]

Results

Particle Size Measurements

The four count median diameters determined from measurements using the Particle Measuring Systems instrument were 0.33, 0.33, 0.34, and 0.37 μm; the respective geometric standard deviations were 1.97, 2.00, 1.96, and 1.81. The five count median diameters calculated from measurements using the MET-1 instrument ranged from 0.38 to 0.63 μm with geometric standard deviations ranging from 1.35 to 2.13.

Hydrogen Chloride Measurements

The results of hydrogen chloride sampling are presented in Tables I and II. Concentrations of hydrogen chloride measured without the hood in place on the day with low (14%) relative humidity ranged from <1 ppm (measured with the smoke tube 24 inches from the tubing inlet leading to the Miran) to 2700 ppm (measured at a distance of 2 inches). The highest concentration measured inside the test hood was also 2700 ppm; this value was achieved during multiple bulb squeezes. Concentrations of hydrogen chloride measured without the hood in place on the day with high (53%) relative humidity ranged from 100 ppm (measured with the smoke tube 6 inches from the tubing inlet leading to the Miran) to 11,900 ppm (measured at a distance of 2 inches). Six measurements of single bulb squeezes made at a distance of 12 inches did not detect hydrogen chloride. The highest concentration measured inside the test hood during multiple bulb squeezes was 14,400 ppm; individual bulb squeezes produced concentrations ranging from 1200 ppm to 10,900 ppm.

Discussion

Qualitative and quantitative tests are used to evaluate the fit of different respirator facepieces to a perspective wearer, which ultimately results in achieving the goal of assigning a single well-fitting facepiece from those evaluated.

Qualitative fit tests are relatively inexpensive and easy to perform, but have a disadvantage of relying on the test subject's response to either the odor of a vapor such as isoamyl acetate (banana oil), the taste of an aerosol such as saccharin, or the irritation of irritant smoke (hydrogen chloride fume). The irritant smoke test is unique in that a test subject usually reacts involuntarily to leakage by coughing or sneezing, and thus the likelihood of giving a false indication of proper fit is reduced.[21,22] Because of their subjective nature, another disadvantage of qualitative fit tests is that they are unable "to rank two or more adequately fitting respirators selectively in order to determine which provides the best fit for a given individual."[23] The use of irritant smoke produced by air flow indicator tubes for facepiece fit testing was first described in 1963.[24] The author noted one advantage of the test: the aerosol produced a fume with a particle size range of 0.5 μm to 3.0 μm. The particle size measurement results reported in this study suggest that the aerosol consists predominantly of submicrometer size particles. The OSHA standards for asbestos (1910.1001), lead (1910.1025), benzene (1910.1028), and formaldehyde (1910.1048) include protocols outlining procedures for the use of irritant smoke that may be used only for testing the fit of half-mask respirators. Each of the protocols in these four standards and the protocol recommended by NIOSH[25] contain a statement that the "protocol may be used to assign protection factors not exceeding ten." When OSHA was considering the amendment to the lead standard to allow employers to choose between quantitative fit testing and one of three qualitative fit testing protocols, data were submitted concerning an irritant smoke protocol in which "the smoke was administered by a squeeze bulb into a hood in which the respirator wearer's head was situated."[26] The data were dismissed as inappropriate, because "OSHA considered this method to be excessively uncomfortable for the wearer."[26]

Some of the protocols outlining procedures for the use of irritant smoke to fit test respirators contain warnings about the possibility of adverse health effects associated with exposure to the fume. The effects of exposure to irritant smoke are described in these protocols as "irritating the eyes,"[27] "very irritating and must be used carefully to avoid injury,"[21,22] and "extremely irritating."[24] These warnings are assumed to be based upon subjective data rather than upon air sampling, since no information was found concerning the levels of hydrogen chloride to which an individual might be exposed in the event of facepiece leak-

TABLE I. Hydrogen Chloride Concentrations Emitted by Smoke Tubes in a Room with Low Relative Humidity

Number of Bulb Squeezes	Distance from Tip of Smoke Tube to Tubing Inlet (inches)	Concentration of Hydrogen Chloride (ppm)
Test Hood not in Place		
1	2	2400
1	2	2700
1	4	650
1	4	1600
1	6	22
1	6	22
1	6	24
1	6	24
1	6	100
1	12	9
1	12	1
1	12	4
1	24	<1
Test Hood in Place		
1	8	510
2	8	200
8 in 15 seconds	8	830
12 in 30 seconds	8	2700
20 in 60 seconds	8	2700
20 in 60 seconds	8	2700

Note: During the testing, the relative humidity was 14% and the temperature was 74°F.

TABLE II. Hydrogen Chloride Concentrations Emitted by Smoke Tubes in a Room with High Relative Humidity

Number of Bulb Squeezes	Distance from Tip of Smoke Tube to Tubing Inlet (inches)	Concentration of Hydrogen Chloride (ppm)
Test Hood not in Place		
1	2	11900
1	2	4300
1	2	8100
1	2	4900
1	4	8400
1	4	5200
1	4	7100
1	4	7500
1	6	100
1	6	600
1	6	1400
1	6	2700
1	12	520
1	12	1700
1	12	460
Test Hood in Place		
1	8	1800
1	8	10300
1	8	10900
1	8	1200
1	8	3700
10 in 30 seconds	8	14400
20 in 60 seconds	8	7100

Note: During the testing, the relative humidity was 53% and the temperature was 75°F.

age during an irritant smoke fit test. In a letter of interpretation concerning the section of the respirator standard addressing fit testing [1910.134 (e) (5) (i)], OSHA stated in a 1990 letter "that the increased incidence of overexposure to toxic substances in the workplace that would occur in the absence of respirator fit testing presents a greater health risk for employees than does the small exposure to sodium saccharin or stannic oxychloride provided by qualitative fit testing protocols."(28) However, the fit testing chapter in the OSHA *Respiratory Protection Program Manual* issued in 1992 contains the statement that "unless the test subject cannot smell the odor of isoamyl acetate, the irritant fume test should not be performed due to the irritant nature of the fume."(29) The results of sampling reported in this study revealed that a smoke tube produces instantaneous concentrations of hydrogen chloride that far exceed not only its ceiling limit (5 ppm),(12–14) but also its IDLH value (100 ppm)(16) and severe toxic endpoint level (309 ppm).(17) There appears to be substantial variations for some of the concentrations of hydrogen chloride shown in Tables I and II for single bulb squeezes from the same distance. Variation in the extent of irritation caused by the smoke from different tubes, presumably caused by variation in the concentrations of hydrogen chloride emitted, has been observed previously.(27) The NIOSH investigators noticed during testing that the visible smoke puffed from a tube was frequently influenced by the air flow of the laboratory fume hood and was drawn away from the tubing attached to the head of the mannequin. This effect was especially noticeable at distances of 12 and 24 inches and could also be an explanation for the variation in sampling results.

NIOSH recommends that a quantitative fit test be used "when facepiece leakage must be minimized for work in highly toxic atmospheres or those immediately dangerous to life or health."(25) Quantitative fit tests do not rely on subjective response, but result in the determination of a value termed a quantitative fit factor.

The NFPA 1500 document contains the statement that "quantitative fit testing is considered to be more precise than qualitative fit testing, but is not considered to be necessary where positive pressure SCBA are used."[1] As mentioned earlier in this report, an irritant fume or odor test is to be conducted to test the seal of positive-pressure SCBA "using an operating SCBA and not just the facepiece and breathing hose disconnected from the rest of the system."[3] The authors of ANSI Z88.5 seemed to consider qualitative fit testing methods to be more practical than quantitative fit testing "because of the expense of the equipment, the training of the operator, size differences among paid departments, and the large number of volunteer departments."[3] Since the publication of ANSI Z88.5 in 1981, the expense of quantitative fit testing equipment has decreased substantially and their operation has been simplified.

Conclusions and Recommendations

Because fire fighting activities frequently occur in "highly toxic atmospheres or those immediately dangerous to life or health,"[25] a quantitative fit test should be used by the fire department. Because the purpose of a fit test is to evaluate the seal between a facepiece and its wearer's face, quantitative fit tests should not be conducted using an operating SCBA. Rather, fit tests should be conducted using the full facepiece air-purifying versions of the MSA Ultravue facepieces that are also used with the MSA Ultralite™ SCBAs. A minimum fit factor should be established that must be achieved before a fire fighter is assigned the best fitting facepiece of the facepieces evaluated. A minimum fit factor of 1000 for negative-pressure SCBA has been recommended for fire departments that perform quantitative fit tests,[3] but the basis for recommending this value is uncertain.

The specific circumstances are unknown that caused skin or eye irritation by fire fighters during qualitative fit tests with irritant smoke. The positive pressure inside the facepiece of a properly functioning pressure-demand SCBA would be expected to be sufficient to prevent leakage of irritant smoke into even a poorly fitting facepiece. If leakage of irritant smoke is assumed to have occurred when a pressure-demand SCBA was being worn, then consideration must be given to the possibility that the regulator of the SCBA was not functioning properly. Therefore, all SCBA used by the fire department should be evaluated to ensure that each one is maintained in accordance with its manufacturer's recommendations.

Finally, the sampling results of this study provide evidence for the first time that high concentrations of hydrogen chloride are emitted from irritant smoke tubes in environments with low and high relative humidity and that exposure to the fume produced by these tubes should be considered an occupational health risk.

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Editorial Note: Steve Lenhart is with the Hazard Evaluation and Technical Assistance Branch and G.E. Burroughs is with the Methods Research Branch of NIOSH. More detailed information on this evaluation is contained in the Health Hazard Evaluation Report No. 93-040-2315 available through NIOSH, Hazard Evaluation and Technical Assistance Branch, 4676 Columbia Parkway, Cincinnati, Ohio 45226; or by telephoning 1-800-35-NIOSH.