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SUMMARY

The National Institute for Occupational Safety and Health (NIOSH) conducted a Health Hazard Evaluation (HHE) in response to a request from the Fire Chief of the Anchorage 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. Each of 186 fire fighters from the Anchorage Fire Department were fit tested in 1992, while wearing a self-contained breathing apparatus (SCBA) (with nose cup) operated in the pressure-demand mode. The fit testing method used by Anchorage 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 tubes used contain stannic chloride ($SnCl_4$), which reacts with ambient humidity to liberate a white hydrochloric acid fume and tin compounds. The health risks associated with the use of irritant smoke were evaluated by: (1) conducting particle size analysis of the "smoke" emitted from air flow indicator tubes, and (2) measuring the concentration of hydrogen chloride produced by these tubes. Count median diameters of the smoke ranged from 0.33 to 0.63 micrometer with geometric standard deviations ranging from 1.35 to 2.13. Concentrations of hydrogen chloride measured without the hood in place on a day with low (14%) relative humidity ranged from <1 part per million (ppm) to 2,700 ppm. The highest concentration measured inside the test hood was also 2,700 ppm; this value was achieved during multiple bulb squeezes. Concentrations of hydrogen chloride measured without the hood in place on a day with high (53%) relative humidity ranged from 100 ppm to 11,900 ppm. The highest concentration measured inside the test hood during multiple bulb squeezes was 14,400 ppm; individual bulb squeezes produced concentrations ranging from 1,200 ppm to 10,900 ppm.

Because fire fighting activities frequently occur in highly toxic atmospheres or those immediately dangerous to life or health, a quantitative fit test was recommended to be used by the Anchorage Fire Department. Fit tests were recommended to be conducted with the full facepiece air-purifying versions of the facepieces that are also used with the SCBAs used by the fire department. The sampling results of this study suggest that high concentrations of hydrogen chloride are emitted from irritant smoke tubes and that exposure to the fume produced by these tubes should be considered a health risk.

KEYWORDS: SIC 9224 (Fire Protection), fire fighting, hydrogen chloride, irritant smoke, respirator fit testing.

INTRODUCTION

The National Institute for Occupational Safety and Health (NIOSH) conducted a Health Hazard Evaluation (HHE) in response to a request from the Fire Chief of the Anchorage 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 final report are: (1) evaluation of the health risks associated with the use of irritant smoke for qualitatively fit-testing respirator facepieces and (2) recommendation of alternative methods 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)]

Each of 186 fire fighters from the Anchorage Fire Department were 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, P.O. Box 426, Pittsburgh, PA). 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 Anchorage involved puffing irritant smoke from Sensidyne air flow indicator tubes (Sensidyne, Inc., 16333 Bay Vista Drive, Clearwater, Florida 34620) into a 3M model FT 14 test hood (3M Occupational Health and Environmental Safety Division, 3M Center Building 275-6W-01, St. Paul, MN 55144-1000), which encompassed the fire fighter's head and the SCBA's facepiece. Sensidyne 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: (1) conducting particle size analysis of the "smoke" emitted from Sensidyne air flow indicator tubes, and (2) measuring the concentration of hydrogen chloride produced by these tubes.

Particle Size Measurements[5]

Particle size measurements of the aerosol emitted from Sensidyne 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, CO), which measures particles ranging from 0.065 micrometer (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 $\geq$0.1 µm to $\leq$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, MA 02035) operated at a pathlength of 20.25 meters and an analytical wavelength of 3.4 micrometers. A 28-inch section of 3/8 inch (inside diameter) flexible tubing was connected from the inlet of the Miran to a 6-inch section of 1/4 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 sub-micrometer particles, the effects 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 each smoke tube being evaluated held at various distances from the inlet of the tubing leading to the Miran. Measurements were also made with a 3M model FT 14 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.

EVALUATION CRITERIA

General Guidelines

As a guide to the evaluation of the hazards posed by workplace exposures, NIOSH investigators employ environmental evaluation criteria for assessment of chemical and physical agents. These criteria are intended to suggest levels of exposure to which most workers may be exposed up to 10 hours/day, 40 hours/week for a working lifetime without experiencing adverse health effects. It is important to note, however, that not all workers will be protected from adverse health effects if their exposures are maintained below these levels. A small percentage may experience adverse health effects because of individual susceptibility, a preexisting medical condition, and/or a hypersensitivity (allergy). In addition, some hazardous substances may act in combination with other workplace exposures, the general environment, or with medications or personal habits of the worker to produce health effects even if the occupational exposures are controlled at the levels established by the evaluation criteria. Also, some substances are absorbed by direct contact with the skin and mucous membranes, and thus the overall exposure may be increased

above measured airborne concentrations. Evaluation criteria typically change over time as new information on the toxic effects of an agent become available.

The primary sources of evaluation criteria for the workplace are: NIOSH Criteria Documents and Recommended Exposure Limits (RELs),[6] the American Conference of Governmental Industrial Hygienists' (ACGIH) Threshold Limit Values (TLVs),[7] and the Occupational Safety and Health Administration (OSHA) Permissible Exposure Limits (PELs).[8] These values are usually based on a time-weighted average (TWA) exposure, which refers to the average airborne concentration of a substance over an entire 8- to 10-hour workday. Concentrations are usually expressed in parts per million (ppm), milligrams per cubic meter (mg/m^3), or micrograms per cubic meter ($\mu g/m^3$). In addition, some substances have only a ceiling limit, a concentration that should not be exceeded during any part of a workday. Other substances have a short-term exposure limit (STEL) to supplement a TWA limit where there are recognized toxic effects from short-term exposures. A STEL is a 15-minute TWA concentration which should not be exceeded at any time during a workday even if the 8-hour TWA is less than the exposure limit. The recommendation of ACGIH for a substance without a STEL is that "excursions in worker exposure levels may exceed 3 times the TLV-TWA for no more than a total of 30 minutes during a workday, and under no circumstances should they exceed 5 times the TLV-TWA, provided that the TLV-TWA is not exceeded."[7] The basic concept is that excursions above a substance's 8-hour TWA exposure limit should be maintained within reasonable limits in well-controlled processes.

NIOSH RELs are based primarily on the prevention of occupational disease. In contrast, OSHA PELs and other standards are required to take into account the economic feasibility of reducing exposures in affected industries, public notice and comment, and judicial review. In evaluating worker exposure levels and NIOSH recommendations for reducing exposures, it should be noted that employers are legally required to meet the requirements of OSHA standards.

Hydrogen Chloride

Hydrogen chloride (CAS number 7647-01-0) is a strong irritant of the eyes, mucous membranes, and skin.[9] "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[10] suggests the protective response is so strong that humans rarely have been submitted to damaging concentrations."[11] Inhalation of hydrogen chloride at concentrations of 5 ppm or more is immediately irritating to the nose and throat.[12] In addition to upper respiratory tract irritation, short-term exposure to relatively low concentrations can also cause coughing and choking.[13] Inhalation exposure of male volunteers to hydrogen chloride at concentrations between 50 and 100 ppm for 1 hour were reported as barely tolerable, and 10 ppm was the maximal concentration acceptable for prolonged exposure.[14] The NIOSH REL, the OSHA PEL, and the ACGIH TLV for hydrogen chloride are a ceiling limit of 5 ppm.[6-8] 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."[7] 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% 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 a 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 2,700 ppm (measured at a distance of 2 inches). The highest concentration measured inside the test hood was also 2,700 ppm; this value was achieved during multiple bulb squeezes. Concentrations of hydrogen chloride measured without the hood in place on a day with high (53%) relative humidity ranged from 100 ppm (measured with the smoke tube 6 inches from

Table I

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

February 17, 1993

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

Table II

Hydrogen Chloride Concentrations Emitted by Smoke Tubes In a Room with High Relativity

March 23, 1993

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

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 1,200 ppm to 10,900 ppm.

DISCUSSION

Protection factors are assigned to various classes of respirators as guidance for respirator selection.[21] Assigned protection factors are used as comparative measures of the minimum level of protection that can be anticipated from a respirator used in a workplace. For example, 10 is the assigned protection factor for a half-mask negative pressure air-purifying respirator equipped with appropriate filters or cartridges, while 10,000 is the assigned protection factor for a pressure-demand SCBA. It is generally assumed that a properly used and properly maintained respirator will provide a level of protection equal to or greater than its assigned protection factor for the vast majority of wearers.[22] One of the most critical factors affecting the level of protection afforded any wearer of a negative-pressure respirator is facepiece fit, since a break in the seal between the facepiece and the wearer's face becomes a location for the direct entry of contaminated air upon inhalation. Because the pressure inside the facepiece of a pressure-demand SCBA remains positive during inhalation even at high work rates, inward leakage of contaminated air through a break in the facepiece seal is much less likely to occur than for a negative pressure respirator. However, facepiece fit is a critical factor that also affects the health and safety of a fire fighter wearing a pressure-demand SCBA, since the decrease in service life caused by outward leakage of air reduces not only time available for fire fighting activities, but also time available for safe exit from a potentially life-threatening environment.

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 Testing

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.[23, 24] 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."[25] The use of irritant smoke produced by air flow indicator tubes for facepiece fit testing was first described in 1963.[26] The author noted that one advantage of the test was that 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 HHE Final Report suggest that the aerosol consists predominantly of sub-micrometer 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[27] contain a statement that the "protocol may be used to assign protection factors not exceeding ten." Interestingly, 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."[28] The data were dismissed as inappropriate, because "OSHA considered this method to be excessively uncomfortable for the wearer."[28]

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,"[29] "very irritating and must be used carefully to avoid injury,"[23, 24] and "extremely irritating."[26] 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 leakage 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."[30] 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."[31]

The results of sampling reported in this HHE Final Report revealed that a smoke tube produces instantaneous concentrations of hydrogen chloride that far exceed not only its ceiling limit (5 ppm),[6-8] 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.[29] 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.

Quantitative Fit Testing

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."[27] Quantitative fit tests do not rely on subjective response, but result in the determination of a value termed a quantitative fit factor. This factor is the ratio of the concentration of a challenge agent surrounding a respirator wearer to the concentration of the challenge agent penetrating the seal between the respirator facepiece and the respirator wearer's face. The facepiece with the highest fit factor of the facepieces evaluated is usually assigned to a perspective respirator wearer, providing the fit factor exceeds a previously established minimum acceptable value. Challenge agents used for quantitative fit testing have included uranine dye aerosol, sodium chloride aerosol, corn oil aerosol, helium, dichlorodifluoromethane (Freon®-12), argon, daughter products of radon, and an oil mist of dioctyl phthalate.[25, 32] The earliest documented attempt to quantify the protection of a respirator was made in the Hygienic Institute of the University of Berlin, and found in volume 68 of the Zeitschrift für Hygiene for 1911.[33] "The industrial dusts being studied were intimately mixed with a suspension of bacterial spores, redried and blown into the air of an experimental chamber. A person equipped with one of the protective devices under examination, and a control individual with no such protection, entered the chamber, the noses of both being plugged with sterile cotton in amount sufficient to filter out the dust contained in the air without interfering too seriously with respiration. At the close of the experiment the cotton was washed in sterile water, gelatin plates were made, and the percentage removal of bacterial spores determined by comparing the count from the cotton in the nose of the unprotected individual with that in the nose of the individual wearing the mask or respirator."[33]

"Aerosol challenge agents represent the current quantitative fit testing standard method."[25] However, a major problem with aerosol-based quantitative fit testing concerns the sampling method used to measure the concentration of a challenge agent penetrating the facepiece seal of a respirator being tested. The results of research studies have suggested that in-facepiece sampling does not provide representative samples. The authors of a study evaluating in-facepiece sampling variables, including sampling probe placement, probe depth, leak site, and breathing distribution between nose and mouth, concluded that such sampling with half-mask respirators produces significantly biased and highly variable concentration measurements.[32, 34, 35] A similar study revealed that in-facepiece sampling is also "inadequate and unsuitable for providing reliable quantitative performance data on full-facepieces."[36] These sampling problems might explain in part why a correlation has not been observed between the results of quantitative fit testing results and the level of protection provided by respirators under actual use conditions.[32]

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 by the development of such devices as the Portacount™ Respirator Fit Tester (TSI Inc., Industrial Test Instruments Group, 500 Cardigan Road, PO Box 64394, St. Paul, Minnesota 55164) and the FitTester 3000 (Dynatech Nevada, 2000 Arrowhead Drive, Carson City, Nevada 89706). The Portacount™ uses a constant flow condensation nuclei counter as a sensor and ambient aerosol (room air) is used as the challenge agent.[37, 38] The device "alternately measures aerosol concentrations inside and outside the respirator by means of a solenoid valve. The instrument calculates the fit factor from average particle counts during 90-second sampling intervals."[39] However, as with other aerosol-based quantitative fit testing methods, a sampling probe must be used to collect the in-facepiece sample. The FitTester 3000 is unique in that it does not require the respirator being evaluated to be probed, but rather is based on exhausting air from a temporarily sealed respirator facepiece to generate and then maintain a constant negative pressure inside the facepiece.[25] A challenge pressure is selected to replicate the mean inspiratory pressure that causes leakage into the respirator under normal use conditions, which makes the test independent of mask volume, mask pliability, leak size and shape, leak location, and leak flow characteristics.[25] A study has been conducted to compare respirator fits measured by this controlled negative pressure method and an aerosol-based method.[40] An important observation in this study was that two subjects were unable to achieve a measurable fit with the negative pressure method while wearing one brand of respirator, while the aerosol-based method indicated high fit factors exceeding 3,200. The author of this report concluded that this discrepancy could have been due to increased sensitivity of the negative pressure system and/or failure of the aerosol-based system to measure leakage because of sampling bias.[40]

CONCLUSIONS AND RECOMMENDATIONS

Because fire fighting activities frequently occur in "highly toxic atmospheres or those immediately dangerous to life or health,"[27] a quantitative fit test should be used by the Anchorage 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 1,000 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 Anchorage 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 a health risk.

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