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# Assessment of the Health Hazard Associated with the Use of Smoke Tubes in Healthcare Facilities

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Of particular concern to facilities engineers and healthcare workers is the evaluation of air flow patterns in or near a respiratory isolation room and negative pressure. The Centers for Disease Control and Prevention recommended the use of smoke tubes for this purpose in the second edition of *Guidelines for Preventing the Transmission of Mycobacterium tuberculosis in Health-Care Facilities, 1994*. This article provides an assessment of the potential for patient and healthcare worker exposure to hazardous levels of acid mist when smoke tubes are used to monitor negative pressure. Three brands of smoke tubes (Sensidyne, MSA, and Dräger) were initially investigated. In a bench-top experiment, air was pushed in 30-ml increments through a smoke tube and into 10 ml of deionized water in a scintillation vial. The hydrogen ion concentration of the solution was measured and the generation rate of acid mist was estimated to be 3.3 mg per 30-ml squeeze. The quantity of hydrochloric acid (9.8 mg) from three 30-ml puffs through Sensidyne smoke tubes would need to be diluted by an air volume of at least 1.4 m<sup>3</sup> to be below the Occupational Safety and Health Administration ceiling limit of 7 mg/m<sup>3</sup>. Because of the equivalency of acid mist generation rate by the three brands of smoke tubes, only Sensidyne air flow indicator tubes (0501) were used in the subsequent study to evaluate the dispersion of hydrochloric acid mist into an experimental room. Three smoke generation rates were evaluated in duplicate. Smoke was generated by pushing air either through one or three Sensidyne smoke tubes using a personal sampling pump at a nominal flow rate of 50 ml/min or through one Sensidyne smoke tube using six 30-ml puffs of the aspirator. The acid mist was directed under the door to the experimental room. Air samples were collected at ten locations. When six 30-ml puffs of air were pushed through a Sensidyne smoke tube and directed under the door to the experimental room, the mass concentration of hydrochloric acid averaged 0.34 mg/m<sup>3</sup> (0.23 ppm) at a distance of 0.68 m (2.2 ft) from the door. Caution should be exercised to prevent inhalation of concentrated acid mist because particles in this size range (0.38 to 0.63 μm) will penetrate deep into the lungs. Also, because of its irritant properties, the amount of smoke needed to verify negative pressure or air flow patterns should be minimized. While the acid mist dissipated extremely fast under these experimental conditions, consideration of the smoke's irritant properties and a hospital patient's respiratory condition must be weighed. In all cases, whenever smoke tubes are used in the indoor environment, dilution of the mist must be provided. JENSEN, P.A.; HAYDEN II, C.S.; BURROUGHS, G.E.; HUGHES, R.T.: AS-

ASSESSMENT OF THE HEALTH HAZARD ASSOCIATED WITH THE USE OF SMOKE TUBES IN HEALTH-CARE FACILITIES. APPL. OCCUP. ENVIRON. HYG. 13(3):172-176; 1998. © 1998 AIH.

The Centers for Disease Control and Prevention (CDC) recently published the second edition of *Guidelines for Preventing the Transmission of Mycobacterium tuberculosis in Healthcare Facilities, 1994*.<sup>(1)</sup> This document emphasizes the importance of the hierarchy of control measures (administrative controls, engineering controls, and personal respiratory protection) in preventing tuberculosis (TB) transmission. Of particular concern to facilities engineers and healthcare workers is the recommendation for the use of smoke tubes in the evaluation of negative pressure and air flow patterns in or near a respiratory isolation room.

If smoke tubes are used, TB isolation rooms and treatment rooms should be checked daily for negative pressure.<sup>(1)</sup> If continuous pressure-sensing devices are used, negative pressure should be verified at least once a month by using smoke tubes or taking pressure measurements. However, caution must be exercised to minimize exposure of workers and patients to irritating or hazardous levels of acid mist. Smoke tubes produce a visible mist of water and acid, which is generated when the moisture in air reacts with the reagent in the smoke tube. In general, two reagents are used for generating smoke: stannic chloride and oleum. Air pushed through smoke tubes containing stannic chloride results in the release of water, tin oxides, and hydrochloric acid, and air pushed through smoke tubes containing oleum results in the release of water and sulfuric acid.<sup>(2-4)</sup> The acid mist exiting the smoke tubes may result in exposures to workers and patients until it has been adequately diluted.

## Monitoring Negative Pressure

The person monitoring the negative pressure in a room should hold the smoke tube near the bottom of the door and approximately 2 inches in front of the door, or at the face of a grille or other opening if the door has such a feature. A small amount of smoke can be generated by gently squeezing the bulb (see Figure 1). The smoke tube should be held parallel to the door and the smoke should issue from the tube slowly to ensure that the velocity of the smoke does not overpower the air velocity. The smoke will travel in the direction of air flow. If the room is at negative pressure, the smoke will travel under the door and into the room (e.g., from higher to lower pressure). If the

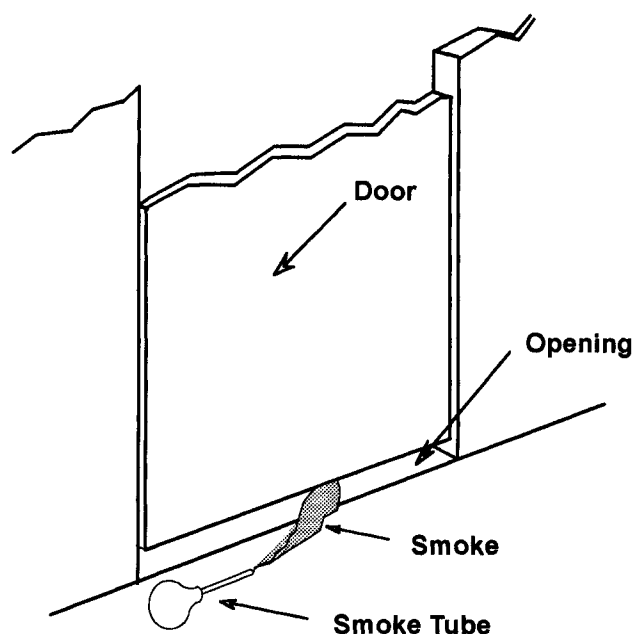


FIGURE 1. Proper location and method for using smoke tubes to determine negative pressure (i.e., air flow into or out of a room).

room is not at negative pressure relative to the smoke generation point, the smoke will be blown outward (positive pressure) or will remain stationary (neutral). This test must be performed while the door is closed. If room air cleaners are present, they should be running. The smoke should not be inhaled directly from the smoke tube (to be discussed below).

#### Occupational Exposure Limits and Health Effects

The current Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) for hydrochloric acid (CAS No. 7647-01-0) is a ceiling of 7 mg/m<sup>3</sup> (5 ppm).<sup>(5)</sup> Although OSHA had removed the ceiling limit in 1989 under the Air Contaminants Standard, the 11th Circuit Court of Appeals vacated this standard in July 1992.<sup>(6)</sup> OSHA is currently enforcing the ceiling limit of 7 mg/m<sup>3</sup>. The National

Institute for Occupational Safety and Health (NIOSH) recommended exposure limit (REL) and the American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit value (TLV) are 7 mg/m<sup>3</sup> (5 ppm) and 7.5 mg/m<sup>3</sup> (5 ppm), respectively, as ceiling concentrations.<sup>(7,8)</sup> The NIOSH immediately dangerous to life and health (IDLH) exposure limit for hydrochloric acid is 75 mg/m<sup>3</sup> (50 ppm).<sup>(9)</sup> In general, hydrochloric acid mists are less harmful than anhydrous hydrochloric acid since the droplets have no dehydrating action. Hydrochloric acid is an irritant to the mucus membranes of the eyes and respiratory tract and is a skin irritant.<sup>(10)</sup> A concentration of 52 mg/m<sup>3</sup> (35 ppm) causes irritation of the throat after short exposure. Although in excess of the NIOSH IDLH limit of 75 mg/m<sup>3</sup>, concentrations of 75 to 150 mg/m<sup>3</sup> have been reported as tolerable for 1 hour.<sup>(10)</sup> This would be dependent on the sensitivity of the individual being exposed. Concentrations of 1500 to 3000 mg/m<sup>3</sup> (1000 to 2000 ppm) are dangerous for even brief exposures.<sup>(11)</sup>

The current occupational exposure limits (OSHA PEL, NIOSH REL, and ACGIH TLV) for sulfuric acid (CAS No. 7664-93-9) are 1 mg/m<sup>3</sup> (0.25 ppm).<sup>(5,7,8)</sup> The NIOSH IDLH exposure limit for sulfuric acid is 15 mg/m<sup>3</sup> (3.8 ppm). The ACGIH short-term exposure limit is 3 mg/m<sup>3</sup> (0.75 ppm). Repeated or prolonged inhalation of a mist of sulfuric acid can cause an inflammation of the upper respiratory tract, leading to chronic bronchitis. Normally, 0.5 to 2 mg/m<sup>3</sup> (0.13 to 0.5 ppm) may be mildly annoying and 6 to 10 mg/m<sup>3</sup> (1.5 to 2.5 ppm) can be unpleasant. A concentration of 40 to 80 mg/m<sup>3</sup> (10 to 20 ppm) is unbearable.<sup>(9,10)</sup>

The current occupational exposure limits (OSHA PEL, NIOSH REL, and ACGIH TLV) for tin (CAS No. 7440-31-5) are 2 mg/m<sup>3</sup>.<sup>(5,7,8)</sup> In general, tin oxides are mild irritants to the skin and mucous membranes.<sup>(9,10)</sup> A listing of three smoke characteristics and criteria for evaluating exposure is shown in Table 1.

#### Methods

##### Acid Mist Generation Rate

Three brands of smoke tubes—Dräger (Pittsburgh, Pennsylvania), Sensidyne (Clearwater, Florida), and MSA (Pittsburgh,

TABLE 1. Listing of the Characteristics of Three Brands of Smoke Tubes and Occupational Exposure Limits for Their Effluent

Manufacturer	Ingredient(s)	Effluent	OSHA	NIOSH	ACGIH
National Dräger, Inc. 101 Technology Drive Pittsburgh, PA 15275 412-787-8389	Oleum (fuming sulfuric acid)	Sulfuric acid	1 mg/m <sup>3</sup> (8-hour TWA)	1 mg/m <sup>3</sup> (8-hour TWA)	1 mg/m <sup>3</sup> (8-hour TWA) 3 mg/m <sup>3</sup> (STEL)
Sensidyne, Inc. 16333 Bay Vista Drive Clearwater, FL 34620 813-530-3602	Stannic chloride	Hydrochloric acid	7.5 mg/m <sup>3</sup> (ceiling)	7.5 mg/m <sup>3</sup> (ceiling)	7.5 mg/m <sup>3</sup> (ceiling)
		Tin compounds	2 mg/m <sup>3</sup> (8-hour TWA)	2 mg/m <sup>3</sup> (8-hour TWA)	2 mg/m <sup>3</sup> (8-hour TWA)
Mine Safety Appliances Co. P.O. Box 426 Pittsburgh, PA 15230 412-967-3000	Stannic chloride	Hydrochloric acid	7.5 mg/m <sup>3</sup> (ceiling)	7.5 mg/m <sup>3</sup> (ceiling)	7.5 mg/m <sup>3</sup> (ceiling)
		Tin compounds	2 mg/m <sup>3</sup> (8-hour TWA)	2 mg/m <sup>3</sup> (8-hour TWA)	2 mg/m <sup>3</sup> (8-hour TWA)

## Smoke Generation Point

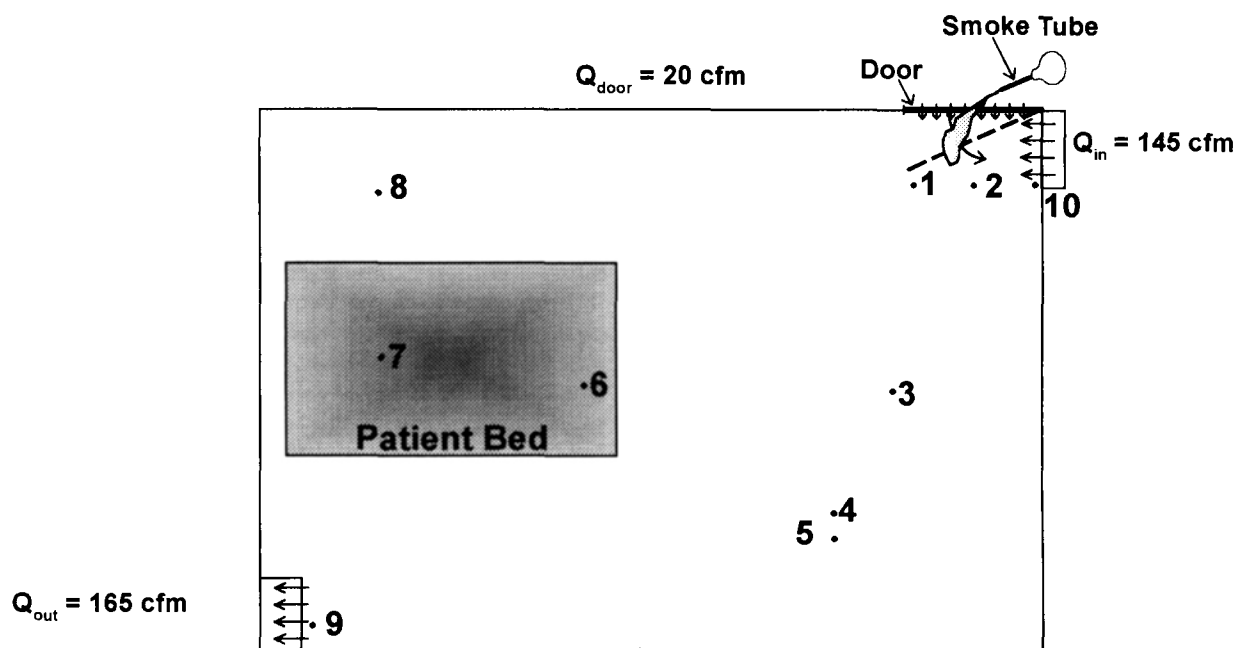


FIGURE 2. Schematic of the experimental room, including location of generation point, door, air supply, air exhaust, patient bed, and sampling locations.

Pennsylvania)—were initially investigated to determine nominal acid mist generation rates and variability between smoke tube brands/types in acid mist generation. The Sensidyne and MSA tubes were supplied with a 30-ml rubber bulb, while the Dräger came with a 55-ml bulb. For the estimation of the acid mist generation rate, a 30-ml volume was used for consistency.

To estimate the acid mist concentration produced from a 30-ml standard squeeze of the smoke tube bulb, a 50-ml plastic syringe was attached to push air in 30-ml increments through a tube and into 10 ml of deionized water in a scintillation vial. Approximately 10 cm of 0.5-cm i.d. Tygon™ tubing was used to attach the syringe to the tube, and an additional 10 cm of 0.1-cm i.d. tubing ran from the end of the tube to the bottom of the vial.

A Corning™ model 340 pH meter (Corning Inc., Science Products Division, Corning, New York) was used to measure the hydrogen ion concentration of the solution after 0, 30, 60, and 90 ml of smoke (corresponding to zero, one, two, and three squeezes of the bulb) had been bubbled through the water at room temperature (22°C). The pH meter was calibrated using Fisher certified buffer solutions of pH 7.00, 5.00, and 2.00 (Fisher Scientific, Pittsburgh, Pennsylvania).

No estimate was made of the collection efficiency of the water for acid mist, although it is identified as an acceptable collection medium in the literature.<sup>(12)</sup> Small diameter tubing was used to minimize bubble size and maximize acid mist/water interaction. Air was pushed through the syringe at a rate of approximately 30 ml/min to increase residence time of the bubbles in the water.

#### Hydrochloric Acid Measurements: Experimental Room

An experimental room 5.2 m long by 3.7 m wide by 2.4 m high (17 ft by 12 ft by 8 ft) was designed by NIOSH researchers to resemble an isolation room in a healthcare facility.<sup>(13,14)</sup> The interior of the room was fitted with a concrete floor, and the plywood walls were coated with paint. The room was designed as a closed system, having a supply air register 0.30 m high by 1.2 m wide (1 ft by 4 ft) on the wall just below the ceiling, near the entrance door, and with an exhaust register 0.30 m high by 0.61 m wide (1 ft by 2 ft) near the ceiling in the opposite corner of the room. The high efficiency particulate air (HEPA)-filtered exhaust air flow rate was 280 m<sup>3</sup>/h (165 ft<sup>3</sup>/min). A portion of the exhaust air was purged [34 m<sup>3</sup>/h (20 ft<sup>3</sup>/min)], and the remainder was recirculated into the experimental room [246 m<sup>3</sup>/h (145 ft<sup>3</sup>/min)] after passing through a HEPA filter. This air flow configuration resulted in approximately six air changes per hour, the minimum air exchange rate recommended by CDC for existing isolation rooms in healthcare facilities.<sup>(1)</sup> The mean temperature and relative humidity were measured to be 24°C and 45 percent using a Rustrak Ranger™ datalogger with a temperature and humidity probe (POD 29/03, Gulton Industries, Inc., East Greenwich, Rhode Island). Preceding the experiments, smoke tubes enabled the researchers to visualize the air currents in the experimental room. Based on this information, the sampling locations identified in Figure 2 were determined. Table 2, second column, lists the height of the sampling location above the floor.

TABLE 2. Sampling Locations and Results for Three Smoke Generation Experiments

Sample Location Number*	Vertical Distance Above Floor m (ft)	Horizontal Distance from Generation Point m (ft)	Hydrochloric Acid Concentration		
			Experiment 1 (mg/m <sup>3</sup> )	Experiment 2 (mg/m <sup>3</sup> )	Experiment 3 (mg/m <sup>3</sup> )
1	0.61 (2)	0.46 (1.5)	0.43	3.4	0.34
2	0.61 (2)	0.30 (1)	0.11	0.43	ND
3	0.61 (2)	1.8 (6)	0.27	0.78	0.09
4	0.91 (3)	2.7 (9)	0.14	0.36	ND
5	1.5 (5)	3.0 (10)	0.07	0.18	ND
6	1.5 (5)	3.4 (11)	0.11	0.20	0.01
7	0.91 (3)	4.3 (14)	0.09	0.15	ND
8	1.8 (6)	4.0 (13)	0.08	0.19	0.11
9	1.8 (6)	6.1 (20)	0.04	0.15	ND
10	1.8 (6)	0.46 (1.5)	0.02	ND	ND

\*Location numbers correspond with those shown in Figure 2.

Because of the equivalency of acid mist generation rate by the three brands of smoke tubes, only Sensidyne air flow indicator tubes (0501) were used in the experiments to estimate generation rate and dispersion of acid mist into the experimental room. Three different smoke generation rates were evaluated in duplicate. Smoke was generated in experiment 1 by pushing air through one Sensidyne smoke tube, using a Dupont model P125 personal sampling pump (E.I. Dupont deNemours, Co., Inc., Wilmington, Delaware) at a nominal flow rate of 50 ml/min for a period of 25 minutes. The smoke was directed under the door to the experimental room. During experiment 2, three Sensidyne smoke tubes and P125 pumps (50 ml/min) were used to generate smoke for a period of 15 minutes. Experiment 3 was designed to simulate a more typical test of negative pressure. Over a 15-minute period, six 30-ml puffs of air were pushed through the Sensidyne smoke tube and directed under the door to the experimental room using the aspirator bulb. To estimate the dispersion of hydrochloric acid into the experimental room, air samples were collected at ten locations (see Figure 2).

Air samples were collected using 200/100-mg silica gel sorbent tubes (SKC 226-10, SKC Inc., Eighty-four, Pennsylvania) and SKC Universal Flow Sample pumps (model 224-PCXR7) calibrated at a nominal flow rate of 0.5 L/min. The samples were obtained over a 30-minute period. Analysis for hydrochloric acid was performed by a contract laboratory using NIOSH Method 7903 (acids, inorganic).<sup>(15)</sup> Hydrochloric acid mist was absorbed onto silica gel in sorbent tubes. The sorbent tubes were sent to a contract analytical laboratory for analysis. The hydrochloric acid was desorbed from each section of the silica gel tubes using 10.0 ml of eluent (0.675 mM

NaHCO<sub>3</sub>/1.98 mM Na<sub>2</sub>CO<sub>3</sub>). The eluent was heated in a boiling water bath for 10 minutes. An aliquot of each sample was analyzed by a Dionex 300 DX ion chromatograph equipped with an HP 1050 autosampler.

**Results**

*Acid Mist Generation Rate*

Table 3 shows that Sensidyne, MSA, and Draeger tubes produced roughly the same acidity (pH) measured by indicating paper when equal volumes (up to 150 ml in 30-ml increments) of smoke were bubbled through 10 ml of water. In subsequent experiments, only the Sensidyne smoke tubes were used.

Table 4 lists the mean pH value of four runs for solutions exposed to 0 to 90 ml of acid mist from Sensidyne smoke tubes. The molar hydrochloric acid concentration was then calculated from the pH value (column 3). This table shows that after 90 ml of smoke had been bubbled through the water (corresponding to three bulb squeezes, estimated to be a maximum likely to be used for this type of testing), the molar concentration of hydrochloric acid was 0.028. In 10 ml of water, the total quantity of hydrochloric acid would be as follows:

$$(0.028 \text{ mmol HCl/ml H}_2\text{O}) \times (35 \text{ mg HCl/mmol HCl}) \\ \times (10 \text{ ml H}_2\text{O}) = 9.8 \text{ mg HCl}$$

This quantity of hydrochloric acid (9.8 mg) would need to be diluted by an air volume of at least 1.4 m<sup>3</sup> to be below the OSHA ceiling limit of 7 mg/m<sup>3</sup>.

TABLE 3. Acidity of Three Brands of Smoke Tube Solutions Measured by Indicating Paper

Smoke (ml)	Sensidyne pH	MSA pH	Draeger pH
30	2.0	2.0	2.0
60	1.5	1.5	1.5
90	1.5	1.5	1.5
150	1.0	1.0	1.0

TABLE 4. Representative Sample of Acidity of Sensidyne Smoke Solutions

Smoke (ml)	Mean pH	[Hydrochloric Acid] (Molarity)
0	7.06	8.8E-08
30	2.17	6.8E-03
60	1.81	1.5E-02
90	1.55	2.8E-02

### Hydrochloric Acid Measurements: Experimental Room

The mean hydrochloric acid concentrations ( $n = 2$ ) for each of the three experiments are shown in Table 2. In all three experiments, the highest mean concentration was observed at location 1, which was close to the generation point and in the visible smoke plume. In experiment 2, where three smoke tubes were used, the highest mean concentration measured was  $3.4 \text{ mg/m}^3$  (approximately one-half of the current PEL). The lowest concentrations, as expected, were noted at the inlet air grille. Overall, the lowest concentrations were noted in experiment 3, which consisted of six 30-ml puffs of smoke (maximum observed concentration was  $0.34 \text{ mg/m}^3$ ).

### Discussion and Conclusions

Variability of hydrochloric acid concentrations between experiments and with regard to location was not studied in a comprehensive fashion. For instance, the difference between measured hydrochloric acid concentrations in experiments 1 and 3 at location 8 is within the variability expected when all factors such as smoke generation and measurement technique, room configuration, and ventilation rates and locations—none of which was studied in an exhaustive fashion—are considered. Prudent designs of negative pressure isolation rooms provide supply ventilation near the doorway and exhaust ventilation near the patient's bed—air moving from the clean (noninfectious) to the less clean (potentially infectious) area of the room. From a hospital patient's point of view, when acid mist is released near the door, air is moved from a less clean (acid mist contaminated) to a clean (patient's breathing zone) area. However, hydrochloric acid concentrations found at locations 6, 7, and 8 (most typical of patient location in the room) are extremely low or nondetectable.

Facilities engineers and healthcare workers often evaluate air flow patterns and negative pressure in respiratory isolation rooms with smoke tubes. However, in the tests where six 30-ml puffs of air through Sensidyne smoke tubes were generated, the highest mean concentration of hydrochloric acid measured in the experimental room was  $0.34 \text{ mg/m}^3$  (0.23 ppm). This concentration was measured at a distance of 0.68 m (2.2 ft) from the release point. The acid mist size distribution was reported to have a count median aerodynamic diameter of 0.38 to  $0.63 \mu\text{m}$  with a geometric standard deviation of 1.35 to 2.13.<sup>(16)</sup> Therefore, caution should be exercised to prevent inhalation of concentrated acid mist because particles in this size range will penetrate deep into the lungs.<sup>(17)</sup> Also, because of its irritant properties, the amount of smoke needed to verify negative pressure or air flow patterns should be minimized.

While the acid mist dissipated extremely fast under these experimental conditions, consideration of the smoke's irritant properties and a hospital patient's respiratory condition must be weighed. In all cases, whenever smoke tubes are used in the indoor environment, dilution ventilation of the mist must be provided.

### Disclaimer

Mention of commercial names or products does not constitute endorsement by the Centers for Disease Control and Prevention.

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