IV. ENVIRONMENTAL DATA AND ENGINEERING CONTROLS

Environmental Data

NIOSH has conducted industrial hygiene surveys of several facilities engaged in the manufacture or use of benzyl chloride [10]. A summary of data collected by personal monitoring at two facilities is presented in Table IV-1. Workplace area concentrations of benzyl chloride were determined using organic vapor and infrared analyzers. Personal samples were collected in charcoal tubes with subsequent solvent desorption and analysis by gas-liquid chromatography and a flame ionization detector. The average 8-hour time-weighted benzyl chloride concentrations related to various work operations were assessed by personal sampling in two plants. The results indicated good precision and accuracy for both the collection and analysis of benzyl chloride, alone or in combination with toluene, a contaminant frequently found in the manufacturing area [10]. These values ranged from 0.01 to 0.14 ppm (0.05 to 0.73 mg/cu m) in one plant and from 0.01 to 0.08 ppm (0.05 to 0.41 mg/cu m) with the exception of one TWA concentration of 3.19 ppm (16.5 mg/cu m) during an instance of facility malfunction in the second plant. Compared to the current Federal TWA limit of 1 ppm (5 mg/cu m), the concentrations found were not regarded as excessive.

An earlier report [67] presented the results of air sample analysis from various points in a benzyl alcohol production facility in the Soviet Union. The highest concentrations of benzyl chloride (0.8-8.0 mg/cu m) were measured at the quality control sampling outlet of the reactor. Measurements obtained during quality control sampling at the level of inhalation 1.5 m from the apparatus, ranged from 0.3 to 2.0 mg/cu m. Sampling at the seal of the mixing apparatus and at the ventilation intake grid also gave relatively high readings (0.66-1.4 mg/cu m and 0.67-1.3 mg/cu m, respectively), possibly because the intake shaft was located close to the benzyl chloride exhaust vent. All samples taken 1.5 m from the apparatus or grid, at inhalation level, contained 0.5 mg/cu m or less.

Sampling and Analytical Methods

(a) Direct-Reading Instruments

No direct-reading instruments are available that would specifically measure airborne benzyl chloride concentrations. Two direct-reading organic vapor analyzers (OVA's) were used in a study of the benzyl chloride levels in two chemical plants [10]. The investigators used one OVA, equipped with a flame ionization detector, to measure the general levels of organic vapors, including benzyl chloride. However, this type of

TABLE IV-1

BENZYL CHLORIDE CHARCOAL COLLECTION TUBE
AIR SAMPLING RESULTS--PERSONAL MONITORING

Job Title	Mean Exposure Time (min)	Mean Vol (liters)	Mean Concentration (ppm)	(mg/cu m)
A* Benzyl chloride chief operator (2)**	319	83	0.07	0.36
B Benzyl chloride chief operator (7)	440	108	0.03	0.16
A Benzyl chloride operator (3)	412	108	0.10	0.52
B Benzyl chloride operator (7)	442	116	0.04	0.21
A Benzyl chloride drumming (2)	408	99	0.03	0.16
B Benzyl chloride material handling (4)	248	62	0.03	0.16
A Benzyl chloride maintenance (3)	360	94	0.09	0.47
B Benzyl chloride maintenance (1)	275	63	0.01	0.05
A Benzyl alcohol operator (4)	410	102	0.02	0.10
A Benzyl cyanide operator (12)	387	100	0.02	0.10
B Crude plasticizer operator (7)	446	112	0.03	0.16
B Refining plasticizer operator (7)	445	110	0.03	0.16
A Quality control sampling (1)	13	4	0.27	1.40
B Quality control sampling (2)	21	6	0.10	0.52
A Quality control sampling (toluene stripper) (1)	33	8	0.02	0.10
B Drum filling (1)	25	7	0.02	0.10

*A or B refers to plant sampled.
**Number in parentheses = number of samples.

Adapted from reference 10

detector has a much lower sensitivity to benzyl chloride, and to any other chlorinated compounds, than it has for hydrocarbons. The other OVA, equipped with an infrared detector, was used to record the concentration of benzyl chloride at a single location continuously.

A new type of OVA, based on ultraviolet photoionization principles, reportedly offers potential for instantaneous measurement of benzyl chloride vapor in the 0.1- to 700-ppm (0.5 to 3,660 mg/cu m) range. There is said to be no lowering in sensitivity due to the chloride. NIOSH has not yet tested this instrument.

A colorimetric detector tube is available that is capable of indicating the presence of benzyl chloride in the 1-10 ppm (5-50 mg/cu m) range [68]. The reaction used is not specific for benzyl chloride because it is based on oxidation by potassium permanganate and fixation of the liberated chlorine with o-tolidine, resulting in a colored product. Other chlorinated chemicals would react similarly. In the presence of other organic vapors, such as ethylene, butadiene, and heptane, some permanganate is consumed, thereby reducing the sensitivity of the method.

Within the limits of their sensitivities, direct-reading instruments might be useful for monitoring areas where benzyl chloride is known to be present, such as in a drumming operation, by warning of imminent hazards, leaks, and control system malfunctions. Some instruments can measure rapidly fluctuating levels. Direct-reading instruments are portable and give immediate results.

(b) Sampling

Liquid absorbents can be used to trap benzyl chloride vapor, and the collected sample can be directly analyzed by colorimetry. An ammonium nitrate solution has been used to collect benzyl chloride in air [69], in the absence of benzene and other aromatics, and in the presence of aliphatic halides. A similar method using pyridine [69] was unaffected by aromatics, but halogenated compounds did interfere. The collection system using pyridine must be kept at 6 C by use of a salt/ice bath, a requirement that limits its use to area sampling. Another report [70] discussed the use of a pyridine-formalin mixture as the absorbing medium, in conjunction with analysis by the Fuziwara reaction. Absorption of benzyl chloride in quinoline has been reported [71] to permit its subsequent colorimetric analysis, even when collected in the presence of benzal chloride and benzotrichloride. To eliminate interference by chlorine in this sampling system, a prefilter made up of two sections of cotton, impregnated respectively with potassium iodide solution (10%) and sodium thiosulfate solution (10%), was used upstream from the absorber.

Organic vapors, including benzyl chloride, were collected near a chlorination plant [72] in absorption tubes containing a granular support of Celite 545 with a stationary phase made of silicone elastomer E301. The collected samples were thermally desorbed directly into a gas chromatographic column. Tests with air containing 1 ppm of benzyl chloride have shown a collection efficiency of 80-100% in the presence of other chlorinated toluene products at 1 ppm and of toluene at 100 ppm. Under similar conditions, silica gel was shown to absorb benzyl chloride so strongly that even after 5 minutes of heating it could not be desorbed.

Activated charcoal is an excellent collection medium because of its nonpolarity and its affinity for organic vapors and gases. Adsorption and desorption efficiencies may vary, however, with different batches of charcoal, so that it is necessary to determine the desorption efficiency (DE) for each new batch of charcoal [73]. In the recommended charcoal tube sampling method [73], a known volume of air is drawn through charcoal to adsorb benzyl chloride. A personal sampling pump with flowrate set at 0.2 liters/minute is used to collect the samples. Appropriate blanks also are prepared. When two or more components are known or suspected of being present, provision of information on the identity of the suspected additional components is required. NIOSH has validated this method [74].

(c) Analysis

Benzyl chloride may be determined quantitatively by colorimetric procedures [69,75]. In one method [69] benzyl chloride is determined after its nitration to 2,4-dinitrobenzyl chloride, and its extraction with methyl ethyl ketone followed by alkalinization with potassium hydroxide. The resulting violet color is measured spectrophotometrically at 570 nm. This method requires at least 40 μg of benzyl chloride, equivalent to sampling 8 liters of air containing benzyl chloride at a concentration of 5 mg/cu m. A similar method employs pyridine heated with sodium hydroxide to yield a yellow-orange color, which is measured spectrophotometrically at 430 nm. It requires at least 0.1 mg of benzyl chloride, equivalent to sampling 20 liters of air at the recommended ceiling concentration.

A third method, useful for the quantitative determination of benzyl chloride in the presence of benzal chloride and benzotrichloride [71], employs a reaction with quinoline, a tertiary amine, to form basic quaternary quinolinium salts. When heated, these salts form yellow cyanine dyes that are spectrophotometrically separable in the ultraviolet range; however, absorbance spectra were not reported. This method was reported to be sensitive to benzyl chloride at 1 μg/ml of sample solution. Benzal chloride and benzotrichloride interfered with the analysis when present in the sample solutions at concentrations greater than 25 μg/ml and 250 μg/ml, respectively. Sampling at a rate of 0.2 liter/minute for 15 minutes would be sufficient to determine benzyl chloride at 1 mg/cu m.

In a method that has some potential, but has not yet been tested in an industrial setting, benzyl chloride samples are collected in a 9:1

pyridine-formalin solution; sodium hydroxide solution is added, and the resulting color measured spectrophotometrically [70]. The presence of formalin stabilized the color, which is measured at 370 nm.

Benzyl chloride also has been determined in air using its ultraviolet and infrared absorption characteristics [71,76]. Calibration curves for benzyl chloride [71] in ethanol indicate that there is a linear relationship between optical density and concentration in the range of 1-15 µg/ml of sample. Long-path infrared analysis is subject to broad-band absorption interferences by water vapor and carbon dioxide, at levels near the recommended ceiling concentration limit. One report [76] estimated that the detection limit for benzyl chloride measured in dry air at 10 atm pressure at 1,269 cm^{-1} (7.88 µm) is 0.8 ppm (4 mg/cu m).

Several gas-liquid chromatographic techniques [72,74,77-81] have been described for the determination of benzyl chloride. These methods must be selected and adjusted for the particular conditions at hand. When other substances are present that may interfere because of similar retention times, it may become necessary to make several determinations using different separation conditions (column packing, column temperature programming, etc) [74]. Benzyl chloride may be analyzed by comparison with appropriate internal standards including carbon tetrachloride [77], tetradecane [82], and n-heptadecane [73].

Gas chromatographs equipped with flame ionization detectors are capable of simultaneous separation and quantitative measurement of selected compounds found in industrial solvent vapor mixtures [80]. Such methods are efficient and accurate. The recommended method [73] for benzyl chloride analysis is an adaption of method No. S-115 that was validated by NIOSH in the range of 2-8 mg/cu m for a 10-liter air sample [74]. The working range of the method is 1.7-50 mg/cu m. By slight modification of the sample collection, preparation, and analytical techniques, it would be possible to detect lower concentrations of benzyl chloride. The compound is extracted from the charcoal using carbon disulfide, and a suitable aliquot is injected into a gas chromatograph equipped with a flame ionization detector. The liquid medium allows multiple gas-liquid chromatographic analyses to be made from one sample [80]. The selectivity of the gas-liquid chromatographic method is sufficient to allow separation of benzyl chloride from other substances that typically may be present, such as toluene, benzaldehyde, benzal chloride, benzotrichloride, and benzoyl chloride. These separations are discussed in detail in several reports [72,77-79,81,82].

Considering the ease of collection, the stability of the sample, and the specificity and sensitivity of the analytical method, the combination of charcoal tubes and gas-liquid chromatography constitutes the preferred method for monitoring benzyl chloride in the industrial environment. Other methods can either provide similar results, or offer the convenience of direct reading, or require only a minimum of investment in equipment. Choices will be dictated by the specific problems of monitoring in any given industrial environment. The recommended charcoal tube sampling and gas-liquid chromatographic analytical methods are described in detail in Appendix I (Chapter IX). When performing benzyl chloride analyses by the recommended method, one must exercise extreme caution at all times because of the toxicity and fire and explosion hazards of carbon disulfide. It can be ignited by hot steam pipes. All work with carbon disulfide must be performed under an exhaust hood.

Engineering Controls

The manufacture of benzyl chloride and its use in a variety of organic synthetic processes are generally performed in closed systems [83]. However, when closed systems are not practical or when leaks develop, workplace exposure to benzyl chloride is possible. The likelihood of exposure increases during handling, transferring, or sampling operations.

A local ventilation or exhaust system may be necessary when benzyl chloride is not used in closed systems. The principles set forth in NIOSH's Recommended Industrial Ventilation Guidelines [84], Industrial Ventilation--A Manual of Recommended Practice [85], and Fundamentals Governing the Design and Operation of Local Exhaust Systems, ANSI Z9.2-1971 [86] should be applied to control atmospheric concentrations of benzyl chloride during those operations when exposure is possible. A flexible local exhaust system, consisting of an 8-inch flexible duct and a 24-inch hood exhausting air at 2,300 linear feet/minute positioned 10 inches above a drum being filled with benzyl chloride, was used to capture vapor emitted from the bunghole of the drum [83]. In another application of local exhaust ventilation during a drum-filling operation, a 4-inch flexible tubing exhausting air at 800 linear feet/minute, also captured vapor being emitted from the bunghole [10]. In transfer of benzyl chloride to or from tank trucks or similar vessels, prevention of spills can be accomplished by purging all lines with nitrogen gas before disconnecting delivery lines. When benzyl chloride is handled in open systems, adequate ventilation is essential to protect employees from potential exposures. Ventilation systems require inspection and maintenance on a regular basis to ensure effective operation. Routine inspection should include face velocity and static pressure measurements of the collecting hood, examination of the air mover and collection or dispersion system, and measurements of atmospheric concentrations of benzyl chloride in the work environment. Any changes in the work operation, process, or equipment that may affect the ventilation system must be promptly evaluated to ensure that control measures provide adequate protection of employees.

In the presence of moisture, benzyl chloride slowly hydrolyzes, forming benzyl alcohol and hydrochloric acid. All facilities require frequent inspection and preventive maintenance to ensure that leaks are detected and repaired to avoid exposure of employees. Piping, exhaust system components, reactor vessels, storage vessels, and containers for benzyl chloride must be made from materials that are corrosion resistant. Most vessels and piping should be fabricated from nickel or high-nickel steel, or lined with glass, lead, or phenolic material. Benzyl chloride readily decomposes in the presence of iron, copper, zinc, aluminum, and various alloys containing these metals. If this reaction occurs in a closed container, benzyl chloride can undergo an exothermic polymerization reaction possibly leading to an explosion. One chemical plant that produced benzyl chloride was destroyed by an explosion and fire [87]. Storage of benzyl chloride requires that measures be taken to exclude water. One technique is to vent storage tanks through a tube containing anhydrous calcium chloride or a similar desiccant. Decomposition and polymerization can be prevented by use of propylene oxide to inhibit the formation of free radicals and to scavenge any hydrochloric acid that may be produced. The useful storage life for benzyl chloride is about 3 months [14].

V. WORK PRACTICES

Work and sanitation practices appropriate to the manufacture, handling, and use of benzyl chloride should be primarily concerned with preventing the inhalation of its aerosol or vapor and preventing skin and eye contact with the liquid. Work practices also are concerned with controlling hazards associated with the raw materials, chlorine and toluene, used in the production of benzyl chloride, and with process byproducts including hydrochloric acid, benzal chloride, and benzotrichloride.

(a) Protective Clothing and Equipment

Protective clothing and chemical safety goggles should be worn by employees subject to skin or eye contact with benzyl chloride. Such protection is particularly important while collecting samples, filling drums and tanks, making process adjustments, or maintaining equipment where it is possible to come into contact with irritating liquids or vapors. Protective clothing should be made of material resistant to benzyl chloride. Gloves made of natural rubber, neoprene, or plastic should be worn by employees when they are handling irritant substances, although the permeability of these materials to benzyl chloride remains to be determined. Aprons and boots of rubber or other appropriate materials are recommended for added protection during material handling and usage operations.

Personal protective clothing, devices, and equipment should be cleaned and inspected on a regular schedule, and replaced when worn or broken. Clothing heavily contaminated with benzyl chloride must be removed immediately, and the employee must shower. A laundry service provided by the employer is recommended for the cleaning of contaminated work clothing. Such service would avoid the risk of carrying benzyl chloride or other irritants into the home environment. Plant personnel involved in laundering should be apprised of the hazards associated with the handling of benzyl chloride. If an outside laundry facility is used, the laundry employer must be advised of the hazards involved in handling clothing contaminated with benzyl chloride and of the requirements to ensure that the laundry employees are not exposed to benzyl chloride. Protective clothing should be stored separately from street clothing in lockers with separate compartments provided for that purpose.

In order to ensure that employee exposure does not occur while engineering controls are being installed or altered, respiratory protective devices as specified in Chapter I must be used during this time. Respiratory protective equipment is not an acceptable substitute for proper engineering controls but should be available in emergencies and for nonroutine maintenance and repair situations.

(b) Sanitation

According to the National Fire Protection Association, benzyl chloride has a lower flammable limit in air of 1.1% by volume, with an autoignition temperature of 585 C [88]. Therefore, smoking must not be permitted where benzyl chloride is manufactured, used, handled, or stored. Use of matches, lighters, or other sources of ignition should be restricted to designated areas. Because benzyl chloride is very irritating to the skin and mucous membranes, eating facilities should be separated from work areas. Employees should follow rules of good personal hygiene. They should wash their hands before smoking, eating, or using toilet facilities. A supply of potable water should be available near all places where there is a potential for contact with benzyl chloride or its irritant derivatives. A water supply may be provided by a free-running hose at low pressure or by emergency showers. Where contact with the eyes is likely, eyewash fountains should be readily available.

(c) Spills and Waste Disposal

Spills and leaks of benzyl chloride can result in the presence of its vapor at hazardous concentrations. Leaks should be stopped and repaired as soon as possible after detection. Each employee engaged in cleanup operations must wear protective equipment and clothing. The objective is to confine a spill to as small an area as possible to avoid needless exposure of employees.

Unless necessary to prevent a fire, benzyl chloride should not be flushed with streams of water, which may disperse the material over a wide area, although water fogs or sprays may be useful to contain the spread of vapor. However, dikes around storage areas and holding ponds for benzyl chloride runoff may make flushing of spills with water practical. Contaminated water may be pumped into holding tanks where the benzyl chloride will slowly hydrolyze to benzyl alcohol and hydrochloric acid. Benzyl chloride should be treated with an alkali such as lime, soda ash, or sodium bicarbonate prior to disposal of wastes to receiving waters or treatment plants.

Large spills should be diked with sand, earth, or other suitable absorbent material. Evolution of benzyl chloride vapor may be quickly suppressed by covering a spill with a foam, which may be followed by hydrolysis and neutralization of hydrochloric acid with alkali. Foam application may be followed by vermiculite or other suitable absorbents. Such absorbents also may be applied directly to spills. Hexamethylene tetramine has been reported to be a rapid and effective neutralizer of benzyl chloride and may be used directly on spills as an aqueous (30-40%) solution. Within a few minutes, a water-soluble quaternary salt, benzyl hexamethylene tetrammonium chloride, forms [83]; it is said that this is safe to handle and that it may be flushed away with water. In the presence of strong bases or acids, the quaternary salt would hydrolyze to benzylamine or to benzaldehyde, respectively (Sommelet reaction 89). Certain materials that will not absorb water but will absorb organic materials may be used for cleanup of spills of benzyl chloride mixed with water. Other materials that nonselectively absorb all liquids may be used when the spill is not mixed with water. After the sorbent materials have been applied, a firefighting foam may be used to cover the entire spill area. The solid sorbents used in cleanup of a spill should be packed into polyethylene-lined drums for subsequent disposal at a Class I landfill site 90 . Filled waste containers should not be allowed to accumulate and should be disposed of frequently. Methods of waste disposal must comply with Federal, state, and local regulations.

(d) Housekeeping and Maintenance

As stated previously, benzyl chloride is corrosive in the presence of traces of water; therefore, equipment for its manufacture and use must be maintained and regularly inspected. Leaking seals should be replaced, and leaking tanks and pipes should be repaired as soon as possible to reduce the possibility of worker exposure and loss of products or other materials. Special precautions are needed to prevent employees from being exposed during maintenance and repair operations. Procedures for draining and flushing lines should be established, and adequate local ventilation should be available. Each employee should wear sufficient personal protective equipment and clothing to prevent skin and eye contact and to minimize inhalation exposure.

Maintenance and repair workers, especially those working on ventilation systems or in enclosed environments, have a high risk of exposure to benzyl chloride and associated chemicals. To minimize or prevent exposure, they must be familiar with the hazards of the materials and with proper work practices, and they must have adequate supervision. Special precautions must be taken when work is to be performed in confined spaces. Entry into confined spaces should be controlled by a permit system. Prior to entry, all sources of benzyl chloride must be sealed off, and the equipment used for handling benzyl chloride must be purged and tested for oxygen deficiency and for the presence of flammable vapors and toxic gases. Purging should be done with nitrogen and followed by flushing with water. Continuous ventilation of the confined space should be maintained throughout the entry period. Personnel entering confined spaces should wear protective clothing, be equipped with a safety harness and lifeline, and use either a self-contained breathing apparatus in pressure-demand mode or a combination supplied-air suit with an auxiliary self-contained air supply. Anyone entering a confined space should be observed by a properly trained and equipped standby worker familiar with emergency procedures, should rescue become necessary. A communication system should be set up among workers involved in the operation. Adherence to good housekeeping and maintenance procedures and practices should minimize fire, accident, and chemical exposure hazards. All equipment should be cleaned on a routine basis to avoid buildup of wastes. To minimize the spread of fire, should one occur, the grounds surrounding work areas should be kept clear of combustibles such as trash and vegetation.

(e) Storage, Handling, and Transportation

Benzyl chloride should be transported and stored in sealed, intact containers. A sealed container is one that has been closed and kept closed to the extent that there is no release of benzyl chloride. An intact container is one that has not deteriorated or been damaged to the extent that benzyl chloride is released. Sealed, intact containers pose no threat of exposure to employees; therefore, it should not be necessary to comply with required monitoring and medical surveillance requirements in operations involving such containers. If, however, containers are opened or broken so that benzyl chloride may be released, then all provisions of the recommended standard should apply.

Benzyl chloride should be kept dry and stored away from direct sunlight or heat and from oxidizing agents. Hydrolysis of benzyl chloride occurs slowly in the presence of moisture but is accelerated by heat. Hydrogen chloride gas released by this reaction may build up to a dangerous pressure. Excessive heat will also cause decomposition of benzyl chloride, releasing toxic vapors and fumes that also could build up to explosive pressures.

Inside storage rooms for benzyl chloride should be constructed in accordance with the requirements of 29 CFR 1910.106. Storage areas should be inspected frequently. Containers of benzyl chloride should be properly labeled. Warning labels indicating the nature of eye, respiratory, and skin irritation hazards must be affixed to any container used to transport or store benzyl chloride. Containers should be opened carefully to avoid release of material due to pressure buildup. Signs should be posted in areas where the material is stored or handled to provide safety and hazard information, exit locations, and requirements for respiratory or other protection. Exits from storage areas should be easily accessible and clearly marked.

Damaged drums should be emptied promptly. The iron from damaged drum linings or bung threads can catalyze reactions leading to a dangerous buildup of hydrogen chloride gas. The storage life of benzyl chloride is only 2-3 months due to the possibility of exhaustion of the inhibitors added to neutralize hydrogen chloride and to scavenge free radicals. Care should be taken, therefore, to rotate supplies of benzyl chloride so that storage time does not exceed shelf life.

Benzyl chloride should be loaded and unloaded only in areas where adequate ventilation can be provided. These operations should be conducted away from any source of heat, flame, or sparks.

(f) Emergency Procedures and First Aid

Drills and instructions in emergency procedures and evacuation should be integral parts of work operations. Employers and employees should continually evaluate and, as necessary, update procedures. Employers should provide all necessary emergency equipment and ensure that it is clearly marked, readily accessible, and maintained in working order; employees and supervisors should know the location of emergency shutoff valves. Full protective clothing including boots and self-contained breathing apparatus should be kept in marked and readily accessible locations.

Emergency showers and eyewash fountains should be located near benzyl chloride work areas. In case of skin or eye contact, the employee should immediately wash the skin thoroughly or flush the eyes with copious amounts of water. Employees should be cautioned against touching or rubbing their eyes while working with benzyl chloride. Heavily contaminated clothing and shoes should be removed at once.

Fires involving benzyl chloride can release toxic gases such as phosgene, hydrogen chloride, and carbon oxides. Employees especially trained in firefighting techniques should be available on each shift. Firefighters should use protective equipment including goggles and self-contained breathing apparatus. Streams of water may serve to disperse benzyl chloride over a wider area; however, water spray or fog, foam, carbon dioxide, or dry chemical extinguishment may be employed. Water spray is effective in dispersing combustion products.

Local fire units and rescue squads should be apprised of the types of emergencies anticipated in the plant. Phone numbers for such emergency assistance must be prominently posted in areas where emergencies might occur.

Alarm systems to alert plant personnel to emergency situations are recommended. Such alarm systems could also be used to signal firefighting teams.

First-aid services should be available, and there should be established procedures for obtaining first aid. Properly trained and qualified individuals should be available to administer first aid. Transportation services to move injured employees to hospitals, clinics, or physicians' offices should be prearranged and understood by supervisors and first-aid personnel. These procedures should be periodically reviewed and, as necessary, updated.

The effectiveness of work practices depends on the knowledge and informed cooperation of employees and employers. Employers must take steps to ensure that: (1) each employee receives adequate instruction and training in safe work procedures, the proper use of all equipment appropriate to the workplace, the proper use of personal protective equipment and clothing, and emergency procedures; (2) each employee periodically receives refresher sessions and drills in order to maintain safe work practices and emergency procedures; and (3) each employee is provided with proper tools and equipment.

VI. DEVELOPMENT OF STANDARD

Basis for Previous Standards

In 1955 [91], the American Conference of Governmental Industrial Hygienists (ACGIH) proposed, and in 1956 [92] adopted, a threshold limit value (TLV) of 1 ppm (approximately 5 mg/cu m) as an 8-hour TWA exposure limit for benzyl chloride.

According to the Documentation of Threshold Limit Values for Substances in Workroom Air [93], this TLV was based in part on data summarized from earlier work [21,22,24] by Flury and Zernik [25], who stated that a 1-minute exposure to benzyl chloride at 16 ppm (83 mg/cu m) was intolerable to humans, and that an 8-hour exposure at 170 ppm (881 mg/cu m) was life threatening to cats. The TLV was also based on comments by Smyth [28] concerning the irritating effects of benzyl chloride on the eye, nose, and throat. Smyth stated: "The 1 ppm threshold limit...is undoubtedly low enough to prevent lung injury." There has been no change in either the recommendation or the TLV documentation since its adoption.

The present Federal standard (29 CFR 1910.1000) for exposure to benzyl chloride in the occupational environment is 1 ppm (5 mg/cu m), expressed as an 8-hour TWA limit, based on the ACGIH recommendations.

Argentina, Great Britain, Norway, and Peru have adopted the US Federal standard [94]. A Maximum Allowable Concentration (MAC) of 5 mg/cu m (1 ppm) has been adopted by Finland, Federal Republic of Germany, Rumania, and Yugoslavia [95]. The MAC for benzyl chloride vapor in the USSR was reduced in 1964 from 50 to 0.5 mg/cu m and has remained unchanged [67].

Basis for the Recommended Standard

(a) Permissible Exposure Limit

Employees exposed to benzyl chloride vapor may experience conjunctivitis [21,27,29] or immediate eye irritation, manifested as a burning sensation and tearing [21,22]. Lung damage and reversible corneal opacity have been reported in animals after 6-8 hour exposures above 800 mg/cu m, concentrations that would be encountered only in emergency situations, [21,22]. The mucous membranes of the nose and upper respiratory tract also may be irritated by benzyl chloride vapor at 180 mg/cu m or above [21,30,96]. The human eye irritation threshold for benzyl chloride vapor has been determined to be 41 mg/cu m for a 10-second exposure [30]. Slight conjunctivitis has been reported in workers after 5 minutes (300 seconds) at 6-8 mg/cu m [29]. Despite the absence in this study [29] of information relating to sampling and analytical methods, to the number or percentage of workers affected, or to possible exposures to other chemicals, the results compare well with those obtained in a controlled laboratory study [30].

The mutagenic potential of benzyl chloride has been investigated in two bacterial test systems [57,59,60]. In the "Ames" test, McCann et al [57,58] classified benzyl chloride as "weakly mutagenic," defined as causing fewer than 0.1 revertants/nanomole. "Nonmutagenic" and "weakly mutagenic" compounds, however, could not be distinguished from one another based on the data and definitions used. Rosenkranz and Poirier [61], whose data generally agree with those of McCann et al, stated that addition of hepatic microsomal activating preparations to the test plates consistently led to negative results in both strains tested, presumably, according to the authors, because of a reaction between benzyl chloride and microsomal protein. Fluck et al [60], using the same E. coli system used by Rosenkranz and Poirier [61], presented data indicative of a nonspecific DNA-modifying effect, as measured by growth inhibition. The results of these studies are only suggestive of a mutagenic potential of benzyl chloride.

Benzyl chloride also has been screened for carcinogenic potential in mice and rats [55,97]. Druckery and coworkers [55] reported that injection-site sarcomas developed in 3 of 14 and 6 of 8 rats administered 51 weekly sc injections of benzyl chloride in peanut oil at 40 mg/kg and 80 mg/kg, respectively. Lung metastases, not further characterized, were found in most of the rats that developed sarcomas after the 80-mg/kg doses. Poirier et al [56], however, giving repeated ip injections of benzyl chloride in tricaprylin at 250 mg/kg, 125 mg/kg, and 50 mg/kg for 8, 12, and 12 injections, respectively, did not find a significant increase in pulmonary adenomas in A/Heston strain mice. The lack of an enhanced rate of pulmonary tumor formation may have been due to the expected differences in rates of absorption and metabolism for benzyl chloride between the sc and ip routes. The screening system used by Poirier et al appears to have some validity, however, since 10 of 16 other low molecular weight alkyl halides tested yielded positive results within the 24-week duration of the study.

Benzyl chloride is a highly reactive chemical that can alkylate in vivo, as confirmed by its rapid conjugation with glutathione in many animal species [41,51,64]. The primary conjugation product, S-benzyl glutathione, is a stable molecule that can, however, be enzymatically degraded. Conjugation essentially terminates the alkylating capability of benzyl chloride and, in mammals, leads to the excretion of the compound as benzyl mercapturic acid [38-40]. An in vitro study by Suga et al [64] indicates that conjugation with glutathione can occur both enzymatically and nonenzymatically in rat liver preparations. The enzymic conjugation reaction is also known to occur in human liver preparations [32] and may also occur in a variety of other human tissues as it does in various animal tissues [41]. The enzymic reaction rate between benzyl chloride and glutathione in human liver was determined to be 0.5 micromoles of thiol lost/minute/g of tissue; therefore, the calculated conjugating capacity of the 1.5-kg human liver for benzyl chloride is approximately 721 micromoles/minute. For this capacity to be exceeded, an airborne benzyl chloride concentration of 5,700 mg/cu m would be necessary, assuming 100% absorption of the vapor.

The presently available data are deemed insufficient upon which to base a firm conclusion as to the carcinogenic and mutagenic potentials of benzyl chloride in occupationally exposed workers. However, the evidence of an efficient detoxification mechanism [32,38-43] suggests that the risk of effects from chronic low-level exposure to benzyl chloride is exceedingly small, probably negligible. The principal effects against which the worker must be protected, and upon which the recommended standard should be based, are the acute irritant effects. The lowest exposure to benzyl chloride reported to induce mild irritant effects in humans is 6-8 mg/cu m for a period of 5 minutes [29]. The present Federal occupational standard (a TWA limit of 5 mg/cu m) allows excursions in excess of the lowest concentrations of airborne benzyl chloride known to produce irritant effects in workers. In order to prevent such excursions, NIOSH recommends a ceiling concentration of 5 mg/cu m based on a 15-minute sampling period. In actual practice, a 15-minute ceiling of 5 mg/cu m is probably equivalent to a significantly lower TWA concentration, perhaps 1-3 mg/cu m. The recommended limit should adequately protect workers from the acute adverse effects of benzyl chloride and also markedly reduce any potential for long-term adverse effects.

(b) Sampling and Analysis

The technology is currently available to sample and analyze for benzyl chloride at the recommended ceiling concentration limit. As discussed and presented in greater detail elsewhere in this document, a charcoal tube method is recommended for personal sampling of airborne benzyl chloride. Gas chromatography is recommended for analyzing the adsorbed benzyl chloride.

(c) Medical Surveillance and Recordkeeping

Several reports of human [21,22,27,29,30] and animal [21,22,34] studies indicate that brief exposure to benzyl chloride vapor is sufficient to cause irritation of the eyes and respiratory tract. A medical surveillance program should include preplacement and periodic medical examinations that give particular attention to respiratory system, skin, and eyes. A preplacement chest roentgenogram and tests of forced vital capacity (FVC) and forced expiratory volume in the 1st second (FEV_1) are recommended to aid the physician in placement of workers with preexisting lung diseases and to establish baseline values of pulmonary function. Periodic FVC and FEV_1 tests are recommended because benzyl chloride is a respiratory irritant that may increase airway resistance after long-term exposure. In addition, medical attention shall be provided for employees accidentally exposed to benzyl chloride. Medical records should be maintained for 30 years after termination of employment.

(d) Personal Protective Equipment and Clothing

Liquid benzyl chloride is reported to be a vesicant [27], and exposure to it could result in severe tissue damage [21,22,98]. Injection site necroses were reported in rats [55] and rabbits [40] given benzyl chloride sc in peanut oil or in gum tragacanth, respectively. Although no specific studies are known to have been conducted on its dermal absorption, benzyl chloride is lipophilic [3] and may be able to penetrate the skin. Benzyl chloride has been said to cause dermatitis [29].

No reports have been found concerning human sensitization to benzyl chloride, but Landsteiner and Jacobs [35] demonstrated the hypersensitivity of guinea pig skin to dermally applied liquid benzyl chloride subsequent to a series of intracutaneous injections of 0.01 mg benzyl chloride in saline solution.

Therefore, precautions must be taken to ensure adequate protection against dermal and mucosal contact with benzyl chloride. Personal protective equipment and clothing, including ocular protective devices and work clothes resistant to the penetration of and chemical action by benzyl chloride, should be available to and worn by workers in areas where exposure to benzyl chloride is likely. Showers and eyewash fountains must be available for immediate use in case of accidental contact.

(e) Informing Employees of Hazards

A continuing education program is an important part of a preventive hygiene program for employees who may be occupationally exposed to hazardous materials such as benzyl chloride. Properly trained persons should periodically apprise employees of possible sources of benzyl chloride exposure, the adverse health effects associated with such exposure, the engineering controls and work practices in use and being planned to limit exposure, and the environmental and medical monitoring procedures used to evaluate the effectiveness of control procedures. Employees should be informed of studies indicating a weak mutagenic potential in bacteria, of the report of tumors in rats injected repeatedly with high doses of benzyl chloride, and of the thorough scientific evaluation by NIOSH of the applicability of these data to the occupational environment. Employers may use other equally effective means for informing employees, such as health and safety booklets or the incorporation of health and safety instructions as integral parts of work protocols.

(f) Work Practices

Because benzyl chloride is a severe irritant and vesicant [27], it is recommended that eating, storing, handling, and dispensing of food be prohibited in areas where benzyl chloride is present. In addition, it is recommended that employees who work with benzyl chloride wash their hands thoroughly before eating, smoking, or using toilet facilities. Employees should be cautioned against touching or rubbing their eyes while working with benzyl chloride. In addition, appropriate work practices, training, and other protective measures should be required, regardless of the concentrations of benzyl chloride in the workplace environment.

(g) Engineering Controls

Engineering controls should be used whenever possible to maintain concentrations of airborne benzyl chloride within the recommended occupational exposure limits. In general, benzyl chloride should be contained in closed systems to prevent release of liquid or vapor to the environment. Exposure to benzyl chloride may be controlled by the use of respirators and protective clothing only during the time required to install adequate controls and equipment, to make process changes, to perform routine maintenance or repair operations, or during an emergency. Respirators should not be used as a substitute for appropriate engineering controls during normal operations.

(h) Monitoring and Recordkeeping Requirements

To ensure that workers are not exposed to benzyl chloride at concentrations which exceed the recommended environmental limit, concentrations in the workplace should be monitored at least annually and within 30 days of any process change likely to result in increased benzyl chloride concentrations. If the concentration of benzyl chloride in the work area exceeds the recommended ceiling limit, personal monitoring should be performed quarterly to ensure the adequacy of control procedures. If the results of personal sampling indicate benzyl chloride concentrations in excess of the recommended environmental limit, personal monitoring should be performed at least weekly and should continue until two consecutive determinations show that the workplace benzyl chloride levels no longer exceed the recommended limit. Quarterly monitoring may then be resumed. Records of environmental measurements should be retained for at least 30 years after employment ends.

VII. RESEARCH NEEDS

Research is needed in the following areas to provide a better scientific basis for a recommended occupational health standard.

(a) Epidemiology

No epidemiologic study on employees working with benzyl chloride has been found; however, NIOSH is in the process of evaluating medical and personnel records obtained from a group of manufacturers to estimate the significance of any effects that may be identified. A retrospective cohort study of a working population exposed primarily to benzyl chloride for a sufficient time (20-30 years) should provide valuable information. Any epidemiologic study should also address the effects of alcohol consumption, smoking habits, and obesity on the assessment of occupational hazards and risks. There should be an attempt to identify a large population chronically exposed to benzyl chloride at low concentrations.

(b) Carcinogenicity

Two studies of the carcinogenic potential of benzyl chloride [55,56] have been reported. These involved ip injection of large doses into mice [56] and sc injection into rats [55]. However, these studies do not provide a substantive basis for quantitating the risk for human populations exposed to benzyl chloride at low concentrations throughout their working lifetimes. Properly designed and conducted studies should be performed on at least two mammalian species by the inhalation and dermal routes over a selected range of concentrations to further determine the risk of neoplastic disease. Also, studies to determine the cocarcinogenic or tumor-promoting potential of benzyl chloride should be performed.

(c) Mutagenicity

Two microbial studies [59,60] have indicated a mutagenic potential for benzyl chloride. However, potential mutagenic effects must be systematically investigated in greater detail with respect to dose, time, and route of exposure in both lower organisms and mammals. Animal tests using a variety of doses, schedules, and routes of administration should be performed to further elucidate any mutagenic potential.

(d) Teratogenicity and Related Reproductive Effects

There are no reported studies of teratogenic or related reproductive effects. Definitive experiments are needed with exposure concentrations approaching the recommended workplace environmental limit to determine the effects of low concentrations of airborne benzyl chloride on the reproductive processes in several mammalian species.

(e) Skin Effects

Benzyl chloride has been characterized as a vesicant. However, the data are incomplete and were mentioned secondarily in the reports. Additional information on the degree and character of skin effects on humans is highly desirable. In addition, long-term repetitive experiments should be performed to confirm the possibility of sensitization or other effects from benzyl chloride contact with the skin. Schedules and experimental designs similar to those used for inhalation studies should be followed.

(f) Long-term Animal Exposure Studies

Short-term animal exposure studies have been reported [21,22,34], but long-term experiments exposing several animal species to benzyl chloride vapor at a variety of concentrations approaching the recommended workplace environmental concentration limit are needed. These studies should simulate occupational exposure conditions of 8-10 hours/day, 4-5 days/week, for 18-24 months, and some of the animals should be maintained until the end of their natural lives. These studies should be properly designed and performed to permit assessment of general condition, biochemical/physiologic parameters, and gross and microscopic examinations of involved organs, including the liver, lungs, spleen, and kidneys and CNS and circulatory system.

Studies also are needed to determine the possible effects of DNA alkylation on rapidly dividing tissue, eg, intestine, bone marrow, and seminiferous tubules.

(g) Metabolism and Distribution

The pathways of metabolic transformation, distribution, and elimination of benzyl chloride as a function of the dose rate and route of administration in mammals and in humans have not been adequately investigated. Both in vivo and in vitro studies should be conducted to determine these pathways. The concentration at which saturation, if any, of the detoxification mechanisms occurs should be determined.

(h) Personal Protective Equipment

Lightweight materials, resistant to benzyl chloride penetration, should be identified for use in protective clothing, boots, gloves, and air-supplied hoods. Materials chemically resistant to benzyl chloride should be identified for use in waste containers, drainage channels, diversion dikes, and floors.