5. POTENTIAL FOR HUMAN EXPOSURE

5.1 OVERVIEW

Ethylene oxide is a gas used in the production of other synthetic chemicals such as ethylene glycol. Gaseous releases of ethylene oxide to the environment are the result of uncontrolled industrial emissions. Less than 1% of the industrial production of ethylene oxide is used as a fumigant and sterilizing agent for a variety of purposes and materials which include hospital equipment and certain food.

Ethylene oxide degrades in both the air and natural water via radical formation and hydrolysis, leading to the formation of glycols, and halogenated alcohols (in the presence of sodium chloride), which in turn degrade into simpler molecules such as carbon dioxide and water. The half-lives of these reactions range from a few hours to less than 15 days, depending on environmental conditions. UV-catalyzed oxidation (in the presence of oxygen and nitrogen dioxide) may also account for some of the ethylene oxide lost in the atmosphere. Ethylene oxide also degrades in wastewater treatment systems with a half-life of about 20 days.

No data are available on the fate of ethylene oxide in soil. Nonetheless, this chemical is expected to either volatilize or be leached due to its high vapor pressure and infinite solubility in water. Soil organisms may also convert it to glycols.

Data on the levels of ethylene oxide in the environment are very limited. There are no data to indicate that ethylene oxide is a common constituent of air or water sources of any type in any geographic location within the United States. Fumigated foods and sterilized hospital equipment may have initially high levels of ethylene oxide, which dissipate and/or degrade into other products within a few days. There are no data on ethylene oxide bioaccumulation in marine organisms.

No data are available to determine the general population's exposure levels to ethylene oxide. Environmental exposures may include ethylene oxide from car exhaust and tobacco smoke. The populations with potentially higher than average risk of exposure to ethylene oxide include sterilization technicians and industrial workers involved in the manufacture and/or use of ethylene oxide.

5.2 RELEASES INTO THE ENVIRONMENT

5.2.1 Air

Ethylene oxide is a synthetically produced gas used primarily in the production of other chemicals by the chemical industry. As a result, most of the releases of ethylene oxide to the atmosphere occur during its storage and handling in industrial settings. Industrial emissions of ethylene oxide are due to uncontrolled fugitive emissions or venting with other gases. Estimates of ethylene oxide losses during production range from 1.3 to 3 million pounds (590 to 1,360 kkg) for 1978 and 1980, respectively, as reported in Bogyo et al. (1980). The same report indicated that losses of ethylene oxide during storage might have been about 143,000 pounds (65 kkg) annually.

Other sources of ethylene oxide air emissions include its production from combustion of hydrocarbon fuels and its release from commodity-fumigated materials, estimated to be about 10 million pounds (4,500 kkg) annually (Bogyo et al. 1980), and losses during disinfection of hospital equipment.

Additional nonquantified sources of air emission of ethylene oxide may be bacterial degradation products, photochemical smog, cigarette smoke and hydrocarbon combustion (Bogyo et al. 1980). Barnard and Lee (1972) and Bogyo et al. (1980) reported finding ethylene oxide in the products of n-pentane combustion, but specific concentrations were not given. EPA (1980) concluded that because pentanes are found in gasoline, significant amounts of ethylene oxide are probably released annually into the atmosphere from automobile exhaust.

WHO (1985) reported that the estimated air emissions due *to* agricultural fumigation and disinfection of medical products were about 2% (about 53,000 tons or 48,000 kkg) of the total ethylene oxide production, which was estimated at about 2.4 million tons (2.2 million kkg) in the United States during 1980. The use of ethylene oxide in hospitals was estimated to be less than 0.02% of the total United States production, or about 500 tons (450 kkg) during 1976 (Glaser 1979).

5.2.2 Water

Ethylene oxide discharges into water also appear to be mostly industry-related. According to EPA (1982a), industrial producers of ethylene oxide estimated that about 800,000 pounds of this compound were discharged into wastewater treatment systems each year in the United States. EPA (1982a) also reported that ethylene oxide was not detected in treated industrial wastewaters discharged into waterways. WHO (1985) also indicated that biological treatment of wastewaters containing ethylene oxide appears to be successful in the removal of this chemical from reaching waterways. Contract Laboratory Program (CLP) statistical data from November 1988 appear to verify this assertion. A review of this data base indicated that of 5,300 water samples collected from 862 sites, only two sites had samples contaminated with ethylene oxide, including a surface water site with a concentration of 28 μg/L and a groundwater site with 21 μg/L (mean of two samples) (CLPSD 1988).

5.2.3 Soil

No discharges of ethylene oxide into the soil are reported in the literature. Although ethylene oxide is a potent fumigant and will kill fungi, viruses, and insects, it is not approved as a soil fumigant. However, since ethylene oxide is infinitely soluble in water, it is likely that the soil environment is exposed to this chemical as a result of the atmospheric scrubdown of rainfall and some uncontrolled discharges of liquid wastes containing this chemical. The Contract Laboratory Program Statistical Database (CLPSD 1988) reported that only six soil samples collected from four different sites, out of 862 total sites, had quantifiable amounts of ethylene oxide (mean: 22 µg/kg) (CLPSD 1988).

5.2.4 Other Sources

Solid or liquid wastes containing measurable amounts of ethylene oxide, as defined in Part 261 of CFR 40 (1984), can be classified as hazardous with ignitable and toxic properties. However, according to Bogyo et al. (1980), no specific wastes containing large amounts of ethylene oxide associated with the manufacture of ethylene oxide have been identified.

5.3 ENVIRONMENTAL FATE

5.3.1 Transport and Partitioning

The primary mode of transport of ethylene oxide is via air emissions into the atmosphere. At atmospheric pressure and room temperature, ethylene oxide exists as a gas due to its very high vapor pressure (1,095 mm Hg at 20°C) and low boiling point (10.4° C) (WHO 1985).

The reported log of the octanol/water partition coefficient (K_{ow}) for ethylene oxide is -0.30 (Hansch and Leo 1979), indicating that ethylene oxide is a very polar chemical. From its chemical and physical properties, it can be inferred that ethylene oxide in soil will volatilize as water evaporates, leach through the soil, or be removed by runoff during rainstorms. It is, therefore, unlikely that ethylene oxide will accumulate in soils or sediments. No data on the accumulation and/or fate of ethylene oxide in the soil environment are available.

EPA (1984b) indicated that there are no data on the bioaccumulation of ethylene oxide in animal tissue.

Although ethylene oxide dissolves in water in any proportion, it also has the tendency to escape (volatilize) due in part to its high vapor pressure. Conway et al. (1983) reported that about 95% of ethylene oxide mixed with water volatilizes within 4 hours (its half-life is about 1 hour).

Ethylene oxide is used as a fumigant for some food commodities. The Environmental Protection Agency (198413) reported the use of ethylene oxide to fumigate cocoa, flour, dried fruits, dehydrated vegetables, fish, and bone meal. However, Meister (1988) listed ethylene oxide as a fumigant and sterilizing agent for only three food products: spices, black walnuts and copra. Currently, EPA has set tolerances for residues on these three items (see Table 7-l).

5.3.2 Transformation and Degradation

5.3.2.1 Air

There is limited information on the fate of ethylene oxide in the atmosphere. EPA (1984b) reported that the most probable path of atmospheric degradation of ethylene oxide is oxidation via free-radical formation, and estimated its half-life in air at 25°C to range from 69 to 149 days, based on data (rate constants and the concentration of OH radicals) obtained by Fritz et al. (1982).

Ethylene oxide also reacts with atmospheric oxygen in the presence of nitrogen dioxide and W light. Studies by Gomer and Noyes (1950) indicated that photocatalyzed chemical decomposition of ethylene oxide would result in the formation of methane, ethane, hydrogen, carbon dioxide, and some smaller amounts of simple aldehydes. Jaffe (1971) examined ethylene oxide decomposition products and postulated that ethylene oxide reacts with W-excited nitrogen dioxide molecules, eventually leading to the formation of acetaldehyde, methane, and carbon dioxide. According to EPA (1984b), measurements of the absolute rate constant, determined to be about 6 x 10^{-16} cm^3/mole/sec by Bogan and Hand (1978) for the reaction between oxygen and ethylene oxide at 27° C, indicate an ethylene oxide half-life of about 1,400 years, assuming an atmospheric oxygen concentration of 25,000 molecules/cm^3. Bogan and Hand (1978) determined the final products of oxygen-W catalyzed ethylene oxide oxidation to be hydrogen, water, carbon monoxide, carbon dioxide, and formaldehyde. Joshi et al. (1982) determined ethylene oxide to have a low reactivity with atmospheric nitrogen dioxide under W radiation and at 25° C. Using ethylene oxide:nitrogen dioxide ratios similar to those found in urban and rural air, these researchers reported the ethylene oxide half-life to be more than 53 hours.

In summary, the few available studies on the photodecomposition of ethylene oxide in the atmosphere suggest that it undergoes measurable rates of degradation into simpler products. However, laboratory estimates of the half-life of ethylene oxide in the atmosphere vary widely.

5.3.2.2 Water

Ethylene oxide hydrolyzes in water to form glycols (Long and Pritchard 1956). Bogyo et al. (1980) reported the hydrolysis rate constant (acid catalyzed) to be about 19.9×10^{-3} L/mol-sec at 30° C. According to the same report, all epoxides, including ethylene oxide, can react with anions such as chloride and bromide in aqueous solutions, forming halogenated alcohols. Conway et al. (1983) determined the half-life of ethylene oxide to range from 12 to 14 days in sterile, deionized and natural river water. They also reported that increased water salinity (up to 3% sodium chloride) decreased the half-life of ethylene oxide to 9 days (Conway et al. 1983), and produced ethanediol and chloroethanol.

According to Anbar and Neta (1967), the degradation of ethylene oxide in water via hydroxyl radicals is very slow, with a computed half-life of about 50 years.

Conway et al. (1983) reported that the half-life measurements for ethylene oxide in sterile and natural river water were not appreciably different. This may be because hydrolytic degradation of ethylene oxide is more rapid than biodegradation of this compound in aqueous media.

5.3.2.3 Soil

No studies on the degradation of ethylene oxide in the soil environment have been located. However, it is likely that ethylene oxide would be found in both the water and vapor phases of the soil environment due to its high vapor pressure and very low octanol/water partition coefficient. Thus, ethylene oxide in the soil is likely to undergo at least some degradation via the same types of mechanisms as those that predominate in aquatic environments.

5.4 LEVELS MONITORED OR ESTIMATED IN THE ENVIRONMENT

5.4.1 Air

There is very little information on ethylene oxide levels in air, but the data available indicate that ethylene oxide does not seem to be a contaminant in ambient air. Hunt et al. (1986) conducted an air quality survey in Texas during 1985 and 1986. Quarterly state and local air quality measurements indicated that ethylene oxide was not detected at concentrations above the detection limit of 0.194 ng/m^3. These authors also reported that ethylene oxide was not detected in a comprehensive air quality survey in the state of California.

5.4.2 Water

There are very limited data on the presence or absence of ethylene oxide in water (drinking water supplies, groundwater, etc.) on a national scale. EPA (1984b) reported a survey showing ethylene oxide at a concentration of 2 mg/L in the effluent of a chemical plant in Bandenburg, Kentucky.

5.4.3 Soil

No data are available on the presence or absence of any significant levels of ethylene oxide in soil. However, DeBont and Albers (1976) reported that ethylene oxide is produced by the metabolism of ethylene by an ethylene-oxidizing bacterium. Also, ethylene is a relatively common volatile hydrocarbon in wet soil, where it can be produced by several species of fungi, bacteria, and actinomycetes (Alexander 1977). Therefore, small but constant levels of ethylene oxide may be present in soils under wet conditions. No data are available on ethylene oxide in soils resulting from uncontrolled releases of ethylene oxide liquid waste or from atmospheric depositions of any kind.

5.4.4 Other Media

Ethylene oxide may be found in tobacco and some food as a result of its use as a fumigant and a sterilizing agent. The Farm Chemicals Handbook (Meister 1988) lists ethylene oxide for use only as a fumigant on three food products: spices, black walnuts and copra. However, ethylene oxide may have been used (and may still be used) as a fumigant for tobacco and some cosmetics. Measurable amounts of ethylene oxide were detected in both fumigated and unfumigated tobacco and its smoke; the ethylene oxide concentration in smoke from unfumigated tobacco was 1 μg/g (Bogyo et al. 1980).

Residual ethylene oxide may be found in foods temporarily, following fumigation. Scudamore and Heuser (1971) reported that ethylene oxide may react with water and inorganic halides (chloride and bromide) from foods and produce glycols and halohydrins. The same researchers concluded that the persistence or disappearance of ethylene oxide and its byproducts in fumigated commodities depends on the grain size, type of foods, aeration procedures, temperature, and storage and cooking conditions. According to Scudamore and Heuser (1971), most experimentally fumigated commodities had levels of ethylene oxide below 1 ppm after 14 days in normal storage conditions. No residues of ethylene oxide were found in commercially fumigated flour or tobacco.

Rajendran and Muthu (1981) reported that concentrations of ethylene oxide in 24-hour aerated foods (wheat, rice, spices, dates and peas) (following a 24-hour fumigation period) ranged from 0 to 3.5 ppm. IARC (1976) indicated that food fumigated with ethylene oxide generally had negligible levels of ethylene oxide within a few hours after fumigation, due primarily to loss by volatilization. However, in spices, ethylene oxide levels ranging from 53 to 116 mg/kg (ppm) and about 25 mg/kg (ppm) at 2 days and 26 days after fumigation, respectively have been reported (WHO 1985).

5.5 GENERAL POPULATION AND OCCUPATIONAL EXPOSURE

The general population's exposure to ethylene oxide may occur via inhalation and food ingestion. There is no information to indicate that ethylene oxide is a common contaminant of drinking water supplies.

Since ethylene oxide is used as a sterilant and fumigant, the potential locations of contaminated air include hospitals (ethylene oxide is commonly used to sterilize medical equipment), libraries, museums, and laboratories. Sources include vapors from certain foods, clothing, cosmetics, and beekeeping equipment (NIOSH 1981).

Sources of exposure of the general population to ethylene oxide may be the by-products of gasoline combustion and cigarette smoke. There is also some evidence that some foods such as flour and spices retain measurable ethylene oxide and by-products several months after fumigation. Ethylene oxide exposure levels of the general population via air, water, or foods have not been found in the available literature or from national surveys and have not been estimated.

Occupational groups exposed to ethylene oxide include workers in ethylene oxide manufacturing or processing plants, sterilization technicians, workers involved in the fumigation of foods, clothing, and cosmetics, and indoor fumigators. OSHA (1988b) estimates that 67,728 workers were exposed to ethylene oxide in 1988. OSHA and ACGIH have established an 8-hour workshift exposure limit of 1 ppm (ACGIH 1986; OSHA 1988b). However, NIOSH (1985b) recommends the exposure level to be 0.1 ppm or less over 8 hours, not to exceed 5 ppm for more than 10 minutes. The odor threshold of ethylene oxide in air is 430 ppm (Amoore and Hautala 1983), which is well above the OSHA PEL (1 ppm). Thus, worker exposure to ethylene oxide can be determined only through routine air monitoring.

Hospital workers and patients may be exposed to residual levels of ethylene oxide from the sterilization of hospital equipment. Some sterilized plastics may retain concentrations of ethylene oxide ranging from 3 to 443 mg/kg (ppm) even after seven days of aeration (WHO 1985).

Other medical equipment such as adhesive dressings and cotton wool pads may also retain ethylene oxide at 2 mg/kg (ppm) or less for 7 to 8 days after sterilization (Dauvois et al. 1982).

5.6 POPULATIONS WITH POTENTIALLY HIGH EXPOSURES

Technicians involved in routine disinfection of medical equipment in hospitals may be exposed to relatively high levels of ethylene oxide. Studies of worker exposures in five hospital sterilization rooms in the United States indicate that the time-averaged exposures range from less than 0.1 to 4.3 ppm, with peaks as high as 795 ppm (Hansen et al. 1984). Brugnone et al. (1985) have reported alveolar concentrations of ethylene oxide to be about 75% of the environmental concentrations of ethylene oxide in a hospital sterilizing unit (0.1 to 7.8 ppm); the OSHA timeweighted-average limit is 1 ppm and the 15-minute excursion limit is 5 mm. Occupational exposure levels estimated by OSHA (1988b) range from 0.08 to 3.97 ppm (8-hour TWA) and 0.24 to 32.2 ppm (15-minute) (see Table 7-l).

According to Flores (1983), workers in chemical manufacturing plants in the United States may also be exposed to high levels of ethylene oxide in air; typical average daily exposure levels ranging from 0.2 to 2.2 ppm were measured during 1979. Some isolated incidents of very high (peak) worker exposures have also occurred as a result of plant breakdowns (Flores 1983; Thiess et al. 1981). It is expected that occupational exposures will be reduced because of recent OSHA regulations (OSHA 1988b).

5.7 ADEQUACY OF THE DATABASE

Section 104(i)(5) of CERCLA, directs the Administrator of ATSDR (in consultation with the Administrator of EPA and agencies and programs of the Public Health Service) to assess whether adequate information on the health effects of ethylene oxide is available. Where adequate information is not available, ATSDR, in conjunction with the NTP, is required to assure the initiation of a program of research designed to determine the health effects (and techniques for developing methods to determine such health effects) of ethylene oxide.

The following categories of possible data needs have been identified by a joint team of scientists from ATSDR, NTP, and EPA. They are defined as substance-specific informational needs that, if met would reduce or eliminate the uncertainties of human health assessment. In the future, the identified data needs will be evaluated and prioritized, and a substance-specific research agenda will be proposed.

5.7.1 Identification of Data Needs

Physical and Chemical Properties. Ethylene oxide is commonly used in the synthesis of many other products, and its basic physical and chemical properties are well known and documented (see Chapter 3). However, data on the properties related to its fate in the environment are less reliable or are totally lacking. For example, there are no recent studies that verify the degradation rates of ethylene oxide in air. Also, there is only one study, Conway et al. (1983), that provides data on the rates of degradation and on water to air transfer of ethylene oxide during the 1980s. There are no data on the fate and transport of ethylene oxide in the soil environment. Since ethylene oxide is a gas and a polar solute in water, these types of data are particularly important for media with water-saturated or near saturated conditions, such as landfills. Data on the rates of microbial degradation and toxicity of ethylene oxide in soils are needed.

Production, Use, Release, and Disposal. Available production, use, release, and disposal data indicate that most ethylene oxide manufactured in the United states is consumed in the synthesis of other chemicals. However, current quantitative data on the amounts of ethylene oxide released to the environment during ethylene oxide production and use are sparse. This information would be helpful in evaluating the effect of industrial practices on environmental levels of ethylene oxide.

According to the Emergency Planning and Community Right to Know Act of 1986 (EPCRTKA), (§313), (Pub. L. 99-499, Title III, §313), industries are required to submit release information to the EPA. The Toxics Release Inventory (TRI), which contains release information for 1987, became available in May of 1989. This database will be updated yearly and should provide a more reliable estimate of industrial production and emission.

Environmental Fate. Data on the fate of ethylene oxide in the atmosphere are limited. The half-life estimates of this chemical should be refined and include measurements in the stratosphere. Since ethylene oxide has been shown to slowly react with oxygen, stratospheric measurements should also include data on the potential impact of ethylene oxide on the ozone layer. Data on the fate of ethylene oxide in the water environment are available but are very limited. More information is needed on the rates of transport of ethylene oxide between water and air. Also, more data on the rates of biodegradation of ethylene oxide in natural environments such as lakes, rivers, groundwater, and soil are needed. Data on the fate of ethylene oxide in the soil environment would be useful. Because all of the ethylene oxide that does not degrade in the atmosphere eventually returns to the soil and water, data on transport and degradation of ethylene oxide would be helpful in determining its potential contamination of water supplies.

Bioavailability from Environmental Media. Ethylene oxide has been shown to be absorbed following inhalation of contaminated air. However, there are no data on absorption after oral or dermal administration of this compound. No information was located on the bioavailability of ethylene oxide from contaminated water, soil, or plant material. These data would be useful in determining potential exposure levels for organisms (humans, animals, and plants) that may have contact with ethylene oxide in these media.

Food Chain Bioaccumulation. WHO (1985) has concluded that ethylene oxide will not bioaccumulate in animals since it is readily metabolized via hydrolysis and glutathione conjugation and excretion. This conclusion was based on the review of several studies in both humans and animals (terrestrial and marine species). No data are available in the literature that indicate that ethylene oxide bioaccumulates in plants. Research on the possible mechanisms of plant uptake, absorption and assimilation of ethylene oxide would be useful since it may be a common and natural constituent in the soil environment, as discussed in Section 5.4.3, and because it is also an atmospheric pollutant.

Exposure Levels in Environmental Media. Neither environmental monitoring nor background data are available for ethylene oxide in soil, air, or water. Ambient concentrations of ethylene oxide are not known in high density urban and industrial areas which have potentially large sources of ethylene oxide such as car exhaust or point sources (industrial). These data would be helpful in determining the ambient concentrations of ethylene oxide so that exposure estimates can be made for the general population.

Exposure Levels in Humans. Available data indicate that some work environments provide continuous exposure to ethylene oxide at levels that may exceed OSHA regulations. Data on other industrial workers such as building and agricultural fumigators and construction workers would be useful.

Estimates of the exposure levels of the general population would also be helpful.

Exposure Registries. No exposure registries for ethylene oxide were located. This compound is not currently one of the compounds for which a subregistry has been established in the National Exposure Registry. The compound will be considered in the future when chemical selection is made for subregistries to be established. The information that is amassed in the National Exposure Registry facilitates the epidemiological research needed to assess adverse health outcomes that may be related to the exposure to this compound.

5.7.2 On-going Studies

No on-going studies related to the potential for human exposure to ethylene oxide were located in the available literature.